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THE EVALUATION OF NEGATIVE FILM SPEEDS IN TERMS OF PRINT QUALITY.*

BY

LOYD A. JONES.

I. INTRODUCTION.

In any discussion of the merits of a picture made by photographic processes, the word "quality" is almost invariably encountered. For instance, such statements as "this picture exhibits excellent photographic quality," or "the quality is very poor" are frequently heard. When an attempt is made to define the word quality as used when referring to a characteristic of a photographic reproduction, many difficulties arise. As a matter of fact, it is probable that it is used in different senses by different individuals and even by the same individual in referring to various aspects of the appearance of the picture. One aspect of the quality of a photographic reproduction depends upon the way in which the scene is lighted. This phase of quality obviously depends upon the skill of the photographer in choosing the time of day and the point of view if the scene be an exterior one illuminated by natural sources. From another point of view the quality of the picture depends largely upon compositional factors, such as the position of objects relative to each other within the scene, the balance between light and shade, etc.

At other times the expression "photographic quality" is most certainly used in referring to the degree of perfection with

* Communication No. 683 from the Kodak Research Laboratories.

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which the photographic picture reproduces in the mind of the observer the subjective impression which he received when looking at the original. This statement, of course, cannot apply if the observer is looking at a picture of something he has never seen, but doubtless he has built up in his mind, as a result of accumulated experience with similar objects, a very definite impression of how he thinks the object would have looked had he seen it.

It seems reasonable to assume that this aspect of photographic quality is dependent largely upon the fidelity with which the *subjective evaluation* of brightness and brightness differences produced in the mind of the observer when viewing the original is reproduced in his mind when he views the reproduction. However, it is not safe to assume, in *all* cases, that a precise reproduction of the original subjective impression is that which the observer would accept as the best possible photographic quality, for he might be more pleased with a reproduced subjective impression into which some distortion has been introduced.

This phase of photographic quality is dependent upon the fidelity with which the brightness and brightness differences in the original are reproduced in the illuminated positive as viewed by the observer and upon certain psychophysical characteristics of the observer's visual sensory and perceptual mechanisms. It is with this aspect of photographic quality, rather than with that depending upon lighting and compositional factors that the present paper will deal.

It is evident that to evaluate this element of photographic quality it is necessary to compare the brightness and brightness differences in the object with those in the illuminated positive and also to determine how closely the subjective impression resulting from an inspection of the illuminated print resembles that obtained when viewing the original. The problem therefore involves the consideration of *subjective* factors in addition to those of a strictly *objective* or *physical* nature. If it were possible to make a direct and quantitative comparison between all relevant characteristics of the subjective impression arising from the inspection of the illuminated positive and those same relevant characteristics of the subjective impression received when viewing the original,

it might be unnecessary in evaluating this aspect of photographic quality, to determine the relationships between the brightness and brightness differences of the original and the illuminated positive. While our knowledge of the psychophysical relationships involved in this problem is sufficient to enable us to predict certain characteristics of the subjective response resulting from a specified stimulus, it is not sufficient to permit a complete solution of this problem. Purely introspectional methods might be resorted to, but unfortunately such methods do not yield results specifiable in quantitative terms. It seems most expedient in the light of our present knowledge to determine the relationships between the brightness and brightness differences existing in the original and those of the illuminated positive and then to express the photographic quality, as determined statistically by using the direct judgments of a large group of observers, in terms of these physical characteristics.

From the physical point of view, a *perfect* reproduction, i.e., perfect *objective* quality, is obtained when the brightness and brightness differences in the illuminated positive are identical with those in the object or scene photographed. However, such a positive would in general fail to reproduce with satisfactory fidelity the subjective impression of the original because of the difference (usually very great) between the visual field environment of the original and that of the positive. The portion of the visual field photographed is usually a very small fraction of the total visual field. When a positive of this small portion is viewed in entirely different surroundings (usually at a very much reduced brightness level), the brightness and brightness differences required to reproduce the original subjective impression may differ vastly from the brightness and brightness differences existing in the original.

The theoretical relationships and the practical methods necessary for computing in physical terms how closely the brightness and brightness differences in the original can be reproduced by a specified photographic process have been known for many years. However, when an attempt is made to apply these methods in practice, it is usually found to be impossible, with the available photographic materials, to

obtain an exact physical reproduction of the brightness and brightness differences existing in many objects of which it is desired to make pictures. This is particularly true when the positive is made on reflecting surfaces, such as paper, which must be viewed by reflected light. Compromises therefore must be made. The magnitude and quality of the compromises which will produce the least detrimental effect upon the final reproduction quality cannot be determined by purely physical methods, but must necessarily be established in terms of their subjective effects.

It is obvious that the physical characteristics of a photographic reproduction are determined not only by the characteristics of the negative materials, the amount of exposure given in making the negative, and the way in which the exposed material is developed, but also by the characteristics of the positive material, its printing exposure, and its treatment in development. In much of the work which has been done in this field up to the present time far too little attention has been paid to the importance of evaluating the characteristics of the negative material in terms of the characteristics of the positive material on which the final print is made. This is particularly true in discussions of the speeds of negative materials. Perhaps one of the most important conclusions to be drawn from the work reported in this paper relates to a more rational evaluation of *effective camera speeds* of negative materials.

Many years ago Hurter and Driffield [1] proposed that the speed of a photographic negative material be defined in terms of the *inertia*. In their original work this was done by multiplying the reciprocal of inertia by a constant for which they used 34. This method of specifying speed has persisted quite generally, especially in England and in this country, but certain modifications have been made so that at the present time the constant 10 is often used rather than the 34 proposed by Hurter and Driffield. As will be shown later in this discussion, the minimum negative exposure that results in the maximum print quality is much less than the inertia value and, moreover, is not proportionally related to the inertia value for different photographic materials. This fact indicates that the inertia can no longer be considered as a valid criterion of effective camera speed.

As distinguished from the *inertia* criterion, Scheiner [2] proposed many years ago to use the *just perceptible density* as a criterion of the speed of photographic materials. According to his proposals a sample of the negative material exposed under specified conditions was examined visually and the speed number computed from the exposure which resulted in a *just visible* silver deposit. This system in effect, therefore, employs a fixed low value of *density* as the criterion of speed. Speed numbers based on the just perceptible density are sometimes referred to as *threshold speeds*.

In Germany quite recently the proposal has been made to express speed in terms of the exposure required to produce a density of 0.1 above fog, it being further specified that the development shall be carried to such an extent as to result in the *maximum* possible value of speed. This method has been elaborated and officially adopted in Germany as the DIN system.[3]

Other fixed values of density have been proposed from time to time as criteria of speed. For instance, it has been suggested that the exposure yielding a density of 1.0 when the material is developed so that the straight-line portion of the characteristic curve has a slope of 1.0 be used as a criterion of speed. Other fixed values of density, such as 0.2, 0.3, etc., have also been proposed.

From the standpoint of tone reproduction theory there seems to be no justification for the adoption of *any* value of *density* as a significant criterion of the speed of a photographic negative material. The primary function of the negative material is to record brightness differences existing in the scene. Density, *per se*, has no significance as an indication of the ability of the photographic material to perform this function. The value of negative density by which any particular object brightness is rendered, as, for instance, the deepest shadow, is of no consequence except insofar as it may have some bearing on the exposure time required to make a print from the negative.

Tone reproduction theory indicates there is only one characteristic of the negative curve that is significant in expressing the capacity of the material to reproduce brightness differences, and it is upon the way in which brightness dif-

ferences are reproduced that the quality of the final positive must depend. This characteristic of the D-log E relationship is the "gradient" or "slope" since this determines the magnitude of the density differences by which *brightness differences* in the object will be rendered in the negative and eventually in the positive made therefrom. The term gradient is used in the previous sentence not in reference to the slope of a curve at a particular point, but rather it implies a consideration of the gradient characteristics throughout the entire used portion of the negative curve. There seems to be little doubt that the most logical and theoretically satisfactory solution of the speed evaluation problem lies in the development of a method by which the effective camera speed is expressed in terms of an exposure which is some function of gradient.

The proposal to use gradient as a criterion of speed is not new. In a previous communication [4] various detailed proposals were discussed and a fairly complete bibliography up to that time was given. While the authors of that paper have been quoted as advocating a fixed minimum limiting gradient as a criterion of speed, they have in fact never advocated such a course. They have expressed their agreement with Sheppard,[5] Luther,[6] and others who are of the opinion that the minimum useful gradient is a variable possibly depending upon more than one factor. The following quotation taken from the communication previously mentioned [4] expressed clearly their position on this point:

"From a consideration of tone reproduction requirements it seems quite certain that the establishment of a suitable minimum gradient value must be based upon a consideration of the distribution of gradient in the reproduction. It seems quite logical to conclude that the amount of contrast compression (or expansion) that can be tolerated in the extreme shadow or highlight regions of the reproduction is determined by the amount of contrast compression or expansion in other parts of the tonal scale. For instance, if the brightness range of the subject is such that a (log) brightness difference of 0.3 near the middle of the tonal scale must necessarily be compressed in the print to a brightness difference of 0.15, corresponding to a compression of a brightness range of one-

half that existing in the object, it seems almost certain that a lower minimum gradient in the extreme shadow and highlight regions will be tolerated than under conditions where no compression (or possibly an expansion) of contrast in other parts of the scale is required."

It seems quite certain that the information the user of a photographic material, particularly the amateur, wishes to have about its sensitivity is how little exposure he can give and still obtain a *good print*. It must be realized that the negative itself is only a means to an end and it makes little difference what its characteristics are, provided a print of satisfactory quality can be made therefrom. Under the vast majority of conditions almost any negative material is sufficiently sensitive so that exposures of satisfactorily short times can be made, even when using lenses of moderate or relatively small apertures. It is only under adverse conditions of lighting that differences between the speeds of commercially available negative materials become important. It seems justifiable, therefore, to conclude that the most satisfactory evaluation of *effective camera speeds* should be based upon the *minimum* exposure which will yield negatives from which *prints* of *satisfactory quality* can be made.

In the previous paragraph the term "satisfactory quality" has been used in referring to photographic prints. Now the question may be asked: What are the characteristics of a satisfactory print? The specific problems involved in answering this question include the determination of the relationship between the purely physical characteristics (brightness and brightness differences) of the object and of the positive (material reproduction); the correlation of these results with the direct observational evaluation of print quality based on a large number of print judgments treated statistically; and the correlation of certain aspects of quality, such as, *excellent* and *just acceptable*, with negative exposure. Before proceeding with these specific problems, it is desirable to review briefly the theory of tone reproduction.

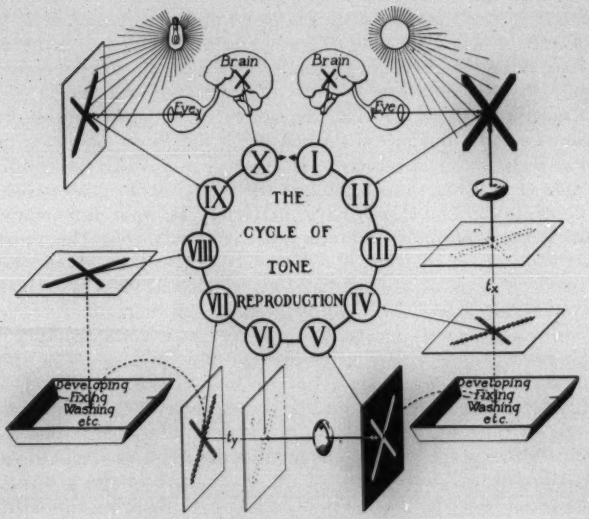
II. REVIEW OF TONE REPRODUCTION THEORY.

The literature of this subject is voluminous. It does not seem advisable in this paper to devote the space required to

present a complete analysis or summary of the contributions of various individuals to this field of knowledge. However, for the convenience of those interested in familiarizing themselves with this material, a fairly complete bibliography is given.[7]

Figure 1 is a symbolical diagram which, although perhaps somewhat fanciful, conveys a more definite picture of the

FIG. 1.



Graphic diagram of the cycle of tone reproduction.

problem as a whole than a mere verbal explanation. For convenience of discussion, the entire cycle of tone reproduction may be divided into ten distinct steps, as indicated by the Roman numerals placed in the small circles near the center of the diagram.

The first aspect may be termed the *subjective object* (I), and by this expression is meant that which the psychologist might term the *object in consciousness*. It is the mental im-

pression or evaluation of the object as perceived. This has certain characteristics which can be evaluated. It is this subjective object which in the last analysis it is desired to reproduce again in consciousness when the observer looks at the picture made through the instrumentality of the photographic processes.

The second element in this cycle of tone reproduction is the illuminated *physical object* (II), an image of which is formed on the retina by means of the refracting elements of the eye. As a result of this image, nerve pulses travel up through the fibers of the optic nerve into the cerebral cortex where, on the arrival of these nerve pulses, the subjective object appears in the consciousness of the observer, this subjective object being projected outward and appearing to exist in the space which constitutes the observer's environment.

The third phase (III) is the *image of the object* formed on the negative sensitive material by some type of image-forming system. This image, when allowed to act through some finite period of time, t_x, produces upon the negative sensitive material a *latent image* (IV), indicated in the diagram by the shaded cross.

The exposed material is then subjected to various chemical operations, such as development, fixation, washing, etc., the result being the fifth step in the cycle, the *negative* (V).

The *image of this negative* (VI) is then formed, either by contact or projection upon the positive sensitive material and this constitutes the sixth step or phase of the series.

The image acting during the period of time, t_y, results in a *latent image* (VII) on the positive material, which, after development, fixing, etc., is converted into a *positive* (VIII), the eighth step in the cycle. When the positive thus produced is illuminated, it becomes the *material reproduction* (IX) and a comparison of the characteristics of this material reproduction with those of the real object (II) constitutes a complete solution of the tone reproduction problem from the *purely objective* standpoint.

An image of the illuminated *material reproduction* is formed on the retina of the observer and creates in his mind an impression which is termed the *subjective reproduction* (X), the last stage in the cycle of tone reproduction. This sub-

jective reproduction, like the subjective object, is a psychological entity arising in consciousness as a result of the arrival of sensory nerve pulses in the cerebral cortex, these pulses having been initiated by the incidence of the image of the material reproduction upon the retina of the observer's eye. Both the *subjective object* and the *subjective reproduction* must be regarded as perceptual in character. This implies that their characteristics are not determined solely by the sensory nerve currents arriving in the cerebral cortex at the time these things are "seen," but depend to a marked extent upon fusion or integrating processes within the cerebral cortex which combine the immediate sensory deliverances with memory records, thus giving rise in consciousness to the perceptual objects.

From a knowledge of the physiological and psychological processes involved in vision, it is quite possible to compare quantitatively certain aspects, particularly the sensory aspects of the subjective object and the subjective reproduction. Such a comparison constitutes a complete solution of the tone reproduction problem from both the *objective* and the *subjective* view-points. In practice it is frequently more convenient to consider the object (II) as the starting point of the cycle and to express the final characteristics of the subjective reproduction *evaluated in terms of the subjective object* as a function of the characteristics of the *physical object.*

The characteristics of II may be compared directly with IX. This constitutes a complete solution of the tone reproduction problem from the purely physical or objective point of view.

A direct comparison of the characteristics of I with X constitutes a complete solution of the tone reproduction problem from both objective and subjective points of view.

For certain purposes a treatment of the objective phase alone is entirely adequate but it should be remembered that any direct experiential evaluation of photographic quality by a method involving the inspection of prints includes at least some subjective factors. It is of course possible in many cases so to adjust conditions of inspection that many effects arising from subjective sources are balanced out or reduced to a negligible minimum.

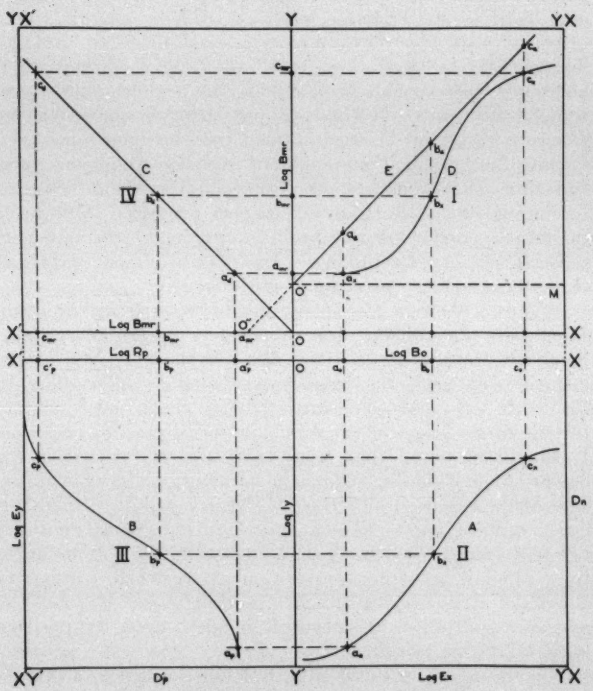
A method whereby the quality of tone reproduction obtainable under some specified set of conditions may be evaluated quantitatively will now be discussed. As fundamental data upon which to base such a solution, information relative to the density-log exposure characteristics of the negative and positive materials is required. These characteristics of course must apply to the materials *as used* in the process. The phrase "as used" is of great importance. If the various characteristics of photographic materials as determined sensitometrically are to be used for predicting or for specifying practical results, it is essential that they be determined with various factors, such as quality of exposing radiation, exposure times and intensities, processing conditions, etc., adjusted to correspond with those existing in practice. Failure to meet these conditions may result in appreciable discrepancies between the results predicted from sensitometric data and those found under operating conditions.

Figure 2 shows a graphic method of treating this problem. It consists of a four-quadrant diagram. In the lower right-hand quadrant is plotted the D-log E characteristic of the negative material, the coördinates being as indicated. In the lower left-hand quadrant is plotted the D-log E characteristic of the material on which the positive is to be made. It should be noted that in plotting this characteristic the density scale is established on the horizontal axis, while in the case of the negative material the density scale is established on a vertical axis. That is, the positive characteristic is rotated through 90 degrees with respect to that of the negative. This is necessary since the negative which consists of a series of areas varying in light-absorbing power becomes the means of controlling the exposure incident upon the positive material during printing.

On the horizontal axis OX are located a series of points, a_0, b_0, and c_0, representing measured brightnesses in various parts of the object being photographed. Vertical lines are dropped from these selected points to intersect the negative characteristics at the points a_n, b_n, and c_n. Through these points horizontal lines are projected to cut the positive characteristics at the points a_p, b_p, and c_p. Vertical lines are drawn through these points cutting the straight line C, in the

upper left-hand quadrant, at the points a_d, b_d, and c_d. The straight line C is drawn through the origin at an angle of 45 degrees. This may be regarded merely as a means of trans-

FIG. 2.



Graphic solution for the objective phase of tone reproduction.

posing the points to the OY axis and is used *only* when the *subjective aspect* of the tone reproduction problem is being *ignored*.

When it is desired to introduce subjective aspects, the straight line C is replaced by a curve into which has been

incorporated the operative subjective factors which must be derived from a knowledge of the conditions existing when viewing the material object and the objective reproduction. These conditions include the brightness and brightness distributions within the total visual field on the two occasions mentioned, the accommodational conditions of the visual receptors, etc.

Horizontal lines drawn through the points thus located on the straight line C intersect with vertical lines drawn through the points a_0, b_0, and c_0 (which represent various object brightnesses) and locate the points a_x, b_x, and c_x. A curve, D, drawn through the points thus established defines the characteristics of the *objective reproduction*. For perfect reproduction of the brightness differences, that is contrast, existing in the object, the curve D must be a straight line at an angle of 45 degrees to the X axis. Such a line is illustrated as the curve E in the upper right-hand quadrant.

The density gradient or slope, G_n, at *any* point on curve A, the negative characteristic, is given by

$$G_n = \frac{dD_n}{d \log E_x}.$$

Likewise, the density gradient, G_p, for the positive material is given by

$$G_p = \frac{dD_p'}{d \log E_y},$$

while the density gradient for the reproduction curve is given by

$$G_{mr} = \frac{d \log B_{mr}}{d \log B_0}.$$

It can be shown by analytical methods that these three quantities, for corresponding points such as b_n, b_p, and b_x, are related by the expression

$$G_n \cdot G_p = G_{mr}.$$

Expressed in words, this means that the gradient in the material reproduction is equal to the product of the corre-

sponding gradients of the negative and positive characteristics. Furthermore, it can be shown that for perfect reproduction of contrast the product of the two gradients, negative and positive, must equal unity, $G_n \cdot G_p = 1.00$.

As will be seen later, many subjects, which it is desired to reproduce by the photographic process, possess a total brightness contrast, the ratio of highest to lowest brightness, considerably greater than can be reproduced by images carried on reflecting surfaces, such as developing-out papers. In such cases correct *proportional* rendering of brightness differences, throughout the entire tonal scale, is obtained when the condition

$$G_n \cdot G_p = k \text{ (a constant less than unity)}$$

is satisfied. Likewise, cases may be encountered where the total brightness contrast in the object is very low. Under these conditions it may be found that the most satisfactory positive is obtained when the ratio of maximum to minimum brightness is appreciably greater than that existing in the object. Under such conditions correct *proportional* rendering is obtained when

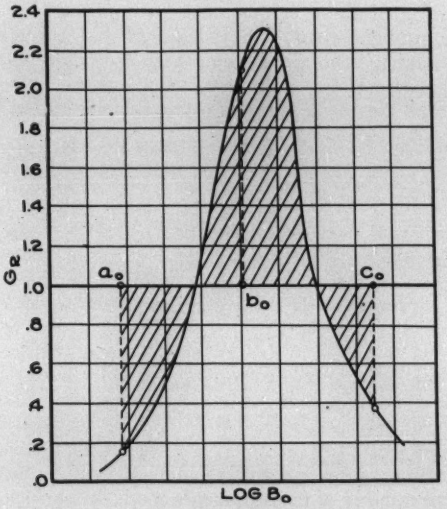
$$G_n \cdot G_p = k \text{ (a constant greater than unity).}$$

When the attempt is made to apply this tone reproduction theory it is found in the vast majority of cases that it is impossible to satisfy the theoretical conditions even for correct proportionality throughout the entire object brightness range. Even when the over-all object contrast is sufficiently low so that it can be duplicated in the reproduction, it may be difficult or impossible to obtain correct proportionality at *all* points on the tonal scale. The reproduction curve shown in Figure 2 is typical of the character of the departures met with in practice, although in this particular case the departures from correct contrast reproduction are considerably greater than can be realized under many conditions.

It is desirable if possible to develop some method by which the magnitude of the failure to reproduce correctly or proportionately the contrast characteristics of the object can be expressed numerically. One such method which has been

suggested [70] is illustrated in Fig. 3. In this figure, the gradient values of the reproduction curve have been plotted as a function of the logarithm of the object brightness. Correct reproduction is of course given by a straight line

FIG. 3.



Curve of gradient errors.

drawn horizontally through the point where G_r is equal to 1.0. If the points a_0 and c_0 represent the minimum and maximum object brightnesses, respectively, then by integrating the shaded areas and dividing by the distance between a_0 and c_0, an average value of the departure from exact contrast reproduction, i.e., the *average gradient error*, ΔG, is obtained. All of these areas must of course be considered as positive.

Whether or not values derived in this manner are true indices of the quality of a print can be determined only by establishing the extent of correlation which exists between statistical evaluations of print quality, based upon direct

judgment of this factor by a large group of competent observers, and the numerical magnitudes of gradient errors. From information already at hand it is quite evident that the actual magnitude of the *average* gradient error will not of itself give the best correlation with statistical judgments, and it seems almost certain that corrective factors based upon the distribution of these errors must be applied. For a given average gradient error, it now appears that the most satisfactory quality is obtained when these errors are balanced, at least approximately, with respect to positive and negative values and also with respect to their distribution between highlight and shadow regions.

III. BRIGHTNESS CONTRAST IN OBJECTS AND IMAGES.

Since many factors involved in the evaluation of photographic quality vary over wide ranges, it seems wise, at least in the preliminary work, to try to make this evaluation for *average* conditions. While considerable information on the brightness contrast in various types of scenes is available, it is scarcely sufficient to warrant drawing any very definite conclusion as to the probable average scene contrast. The brightness distribution in about 150 outdoor scenes has been determined in these Laboratories. The ratio of maximum to minimum brightness was found to vary from about 2 to something over 1000. These very high and low values, however, are not found frequently. Goldberg [7j] has reported on a large number of measurements made on various types of scenes, both indoor and out. From a consideration of all the information available, it appears that the *average* object contrast probably lies somewhere between 50 and 100.

When an image of an object is formed on a photographic material in a camera, the ratio between the highest and lowest image illumination is, in general, less than the same ratio for the object being photographed. This results from several causes, such as reflections at the free glass-air surfaces of the lens system, reflection of light within the body of the camera, and reflection from diaphragm, shutter, and lens barrel elements. On this subject, also, Goldberg[7j] has reported the results of many measurements. A consideration of these, together with some further determinations made in these

Laboratories, leads to the conclusion that probably the *average image contrast* lies somewhere in the neighborhood of 32.

In Fig. 4 is shown a reproduction of a scene the brightness of which is considered to correspond approximately to the

FIG. 4.

The "Willow Pond" scene showing the points at which the density measurements were made on the negatives.

statistical average.[9] When this was photographed with a camera and lens combination known to have approximately average (perhaps somewhat less than average) flare characteristics, the contrast in the image was found to be 28, that is, approximately equal to the value assumed above to represent a reasonable average for image contrast. The image illuminations, I_i (in meter candles), incident on the photographic material, as determined by photographic photometry, at points corresponding to various parts of the composition are as shown in Table I.

TABLE I.

Distribution of Brightness in Image and Object

Spot No.	Location	I_i	Log I_i	I_{io}	Log I_{io}	$B_o(p)$
1	Tree trunk, in shadow	0.45	$\bar{1}.65$	0.22	$\bar{1}.34$	45
2	Tree trunk, in shadow	0.45	$\bar{1}.65$	.22	$\bar{1}.34$	45
3	Shadow under porch	.57	$\bar{1}.76$	.34	$\bar{1}.53$	69
4	Shadow in front doorway	.72	$\bar{1}.86$	.49	$\bar{1}.69$	100
5	Wall in shadow	1.04	0.02	.81	$\bar{1}.91$	166
6	Shadow on water, left of centre	1.40	0.15	1.17	0.07	240
7	Gable in shadow	2.68	0.43	2.45	0.39	500
8	Wall of circular tower	2.68	0.43	2.45	0.39	500
9	Lawn, centre	2.68	0.43	2.45	0.39	500
10	Lawn, left	2.68	0.43	2.45	0.39	500
11	Lawn, right	3.70	0.57	3.47	0.54	710
12	Wall in sun, above awning	7.50	0.88	7.27	0.86	1490
13	Sky above gable	9.50	0.98	9.27	0.97	1900
14	Awning in sun	12.50	1.10	12.27	1.09	2500
15	Sky through trees	12.50	1.10	12.27	1.09	2500
	Contrast	28	1.45	56	1.75	56

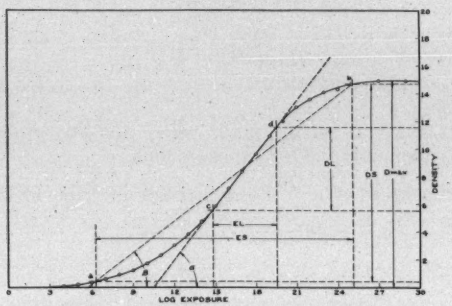
IV. SENSITOMETRIC CHARACTERISTICS OF NEGATIVE AND POSITIVE MATERIALS.

Methods for measuring and specifying the characteristics of photographic materials have been developed and refined to a relatively high state of perfection. Certain conventions have been adopted in specifying these characteristics in numerical terms and it will be convenient to use some of these in further discussion of this subject. A brief review of the nomenclature which has been established on previous occasions will be useful.

In Fig. 5 the S-shaped curve represents in a general way the relation between density and log exposure for both negative and positive photographic materials. On this curve four points, *a*, *b*, *c*, and *d* have been located and various characteristics are specified in terms of the coördinates of these points. The points *a* and *b* are located where the gradient, $dD/d \log E$, of the curve is equal to 0.2. This value of gradient was chosen originally on the assumption that any gradient less than 0.2 is not useful for the reproduction of detail and hence should serve as limits of the *total useful scale*. As will be seen later, this assumption is not entirely justified. The total useful scale of a material is not limited by points having fixed gradient values and the actual

limiting gradients may be somewhat less or somewhat greater than the 0.2 used in establishing the points *a* and *b*. However, for the purposes of establishing approximate values of *total scale*, the points *a* and *b* have been found to be useful.

FIG. 5.



Generalized density-log *E* relationship of photographic materials.

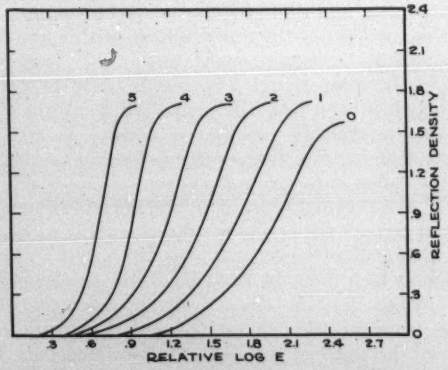
The points *c* and *d* are located at the beginning and the end of that portion of the curve which, within the limits of experimental error, is a straight line. The portion of the curve lying between *a* and *c* is convex with respect to the *X* axis and has been frequently referred to as the *region of underexposure*. Within this region density is not directly proportional to log *E*. The portion between *c* and *d* has been frequently called the *region of correct exposure*, and here *D* is directly proportional to log *E*. The portion between *d* and *b* has been termed the *region of overexposure*, and here again the proportionality between *D* and log *E* fails. From the conclusions which must be drawn later in this discussion, it will be obvious that the terms underexposure, correct exposure, and overexposure are not particularly significant, and, in fact, in the light of our present knowledge are distinct misnomers. The terms *toe*, *straight-line*, and *shoulder* have been used in some cases when referring to these three regions and are much to be preferred to those mentioned previously. While it is impossible to express the complete significance of

the D-log E curve in terms of a small number of numerical values, the following have been found useful for expressing numerically some of the more important characteristics of photographic materials:

Exposure scale, $ES = \log E_b - \log E_a$.
Exposure latitude, $EL = \log E_d - \log E_c$.
Density scale, $DS = D_b - D_a$.
Density latitude, $DL = D_d - D_c$.
D_{max} = maximum density.
Gamma, $\gamma = \tan \alpha$.
Inertia, $i = E$ at the point where the straight line extended cuts the log exposure axis.
Inertia speed, $S_i = \frac{1}{i} \times k$ (a constant, for which 10 is frequently used).

There are a large number of different kinds of developing-out papers available commercially, and these differ among

FIG. 6.



Characteristic curves of developing-out papers, six contrast grades.

themselves to quite an extent with regard to sensitometric characteristics. However, the majority of these materials

which are used extensively in the amateur field have certain typical similarities and in this paper the discussion is confined to the use of a group of six widely used materials of this type. The characteristic curves for these six materials are shown in Fig. 6. These are all glossy surface materials, the emulsion used in their manufacture being adjusted to give a series of "contrast" grades. It will be noted that the maximum density is approximately the same for the entire group, being of the order of 1.70. The steepness of the curve in general increases progressively from grade 0 to grade 5. It will be noted that these materials are characterized by relatively short straight-line portions, long sweeping toes, and rather sharply curved shoulder regions. It is important to note also that the straight-line portion (maximum gradient) extends almost to the maximum density of the material. This fact has an important bearing on the quality of tone reproduction obtainable. Numerical values will be presented in Table II where they can be compared conveniently with each other and with the characteristics of a typical negative material.

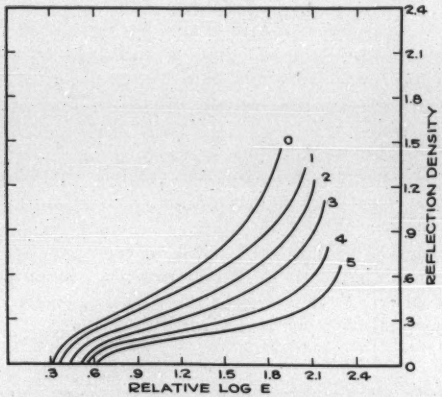
V. HYPOTHETICAL NEGATIVE CHARACTERISTIC GIVING PERFECT TONE REPRODUCTION.

It is now of interest to compute, by means of the tone reproduction diagram, the characteristics of the negative materials which, when used with the positive materials shown in Fig. 6, will give *perfect* objective tone reproduction, that is, a tone reproduction curve that is a straight line and has a gradient of 1.0.

The six negative characteristics "fitting" the six positive characteristics just shown are given in Fig. 7. It follows from the geometrical construction of the tone reproduction diagram that the negative and positive characteristics which together give *perfect* tone reproduction must be mirror images of each other, when the density and the log E axes of the two characteristic curves are oriented as shown in Fig. 2. It will be seen that, in order to fit the sharply breaking shoulder region of the positive materials, the negative characteristic must begin, in the region of low exposure, with an extremely high gradient which then decreases, as shown by the lower

portions of the curves in Fig. 7. The gradient must remain constant for a relatively short log exposure range and then gradually increase again to a very high value in order to fit

FIG. 7.



Hypothetical negative characteristics giving perfect objective tone reproduction when used with the corresponding positive materials shown in Fig. 6.

the low gradient values in the extreme toe region of the positive characteristics.

It will be realized that these curves do not look anything like the D-log E characteristics of available negative materials. This is confirmed by inspection of the D-log E characteristics, Fig. 8, for a negative material used extensively in the amateur field. The five curves shown represent the characteristics obtained for progressively increasing development times. It is obviously impossible to obtain the shapes as shown in Fig. 7 by using any portions of these characteristic curves. It seems impossible, therefore, to expect to obtain *perfect* tone reproduction over the *entire range* of the log exposure scale of the positive material under consideration.

The case, however, is not quite as hopeless as it seems, for certain portions of the positive characteristic can be discarded without interfering materially with the quality of the final

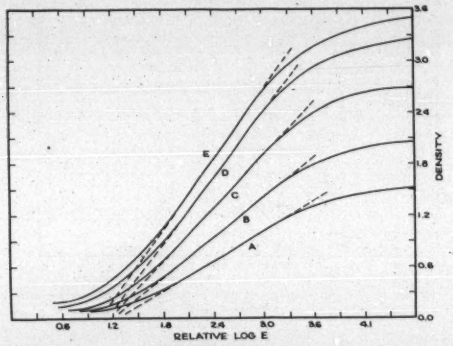
reproduction. Assumptions that permit some limitations will now be made:

(*a*) The object to be reproduced has a brightness contrast of 32 (log contrast = 1.5).

(*b*) The camera and lens system are entirely free from flare light.

(*c*) A highlight density of 0.05 can be tolerated. This density is so low that it very satisfactorily represents a highlight or white.

FIG. 8.



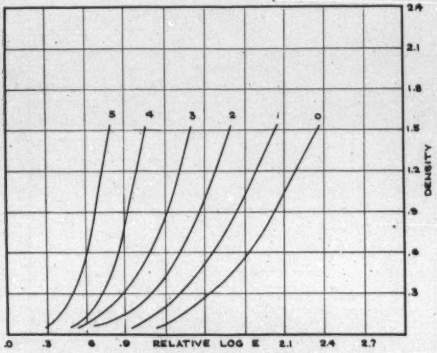
Actual *D*-log *E* characteristics, for various times of development, of a commercially available negative material.

(*d*) Black or the deepest shadow can be satisfactorily represented by a density of approximately 1.55. Experience has shown that with this value of density in the deepest shadow a satisfactory "black" is obtained giving a print which has ample brilliance and does not appear to be flat or "smoky."

It is now possible to determine, on the basis of these limitations, just what portions of these positive materials will be used, Fig. 9. It will be noted that, by accepting a highlight density of 0.05, it is unnecessary to use the extremely low gradient portion of the toe, and that if the maximum density is limited to 1.55, it is furthermore unnecessary to use the entire shoulder part of the curve. It is

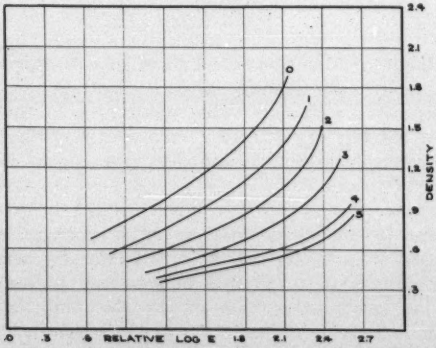
now possible to compute the D-log E characteristics for the negatives which, when used with the positive materials as shown in Fig. 9, will give exact tone reproduction throughout the entire brightness scale. These are shown in Fig. 10. It is now unnecessary to have extremely high gradients in

FIG. 9.



Characteristic curves for various contrast grades of developing-out papers between $D = 0.05$ and $D = 1.55$.

FIG. 10.



Hypothetical negative characteristics giving perfect reproduction when used with corresponding positive curves shown in Fig. 9.

the toe region and the necessary gradient in the highlight region is materially reduced. Looking again at the characteristics of the typical negative materials as shown in Fig. 8, it is possible to select regions which approach fairly closely to those required by the theoretical curves shown in Fig. 10.

Before leaving this phase of the subject it may be of interest to compare the relative characteristics of the positive and negative materials which have just been discussed. In the first section of Table II are numerical values relating to

TABLE II.

Sensitometric Characteristics of Typical Negative and Positive Materials

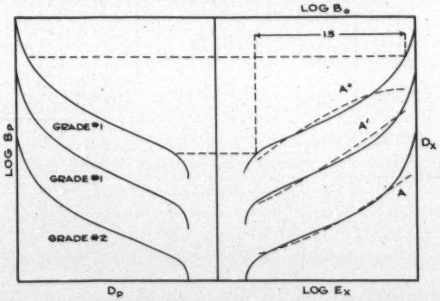
	Positive Material						Negative Material				
	0	1	2	3	4	5	*A*	*B*	*C*	*D*	*E*
ES	1.40	1.37	1.32	1.14	0.84	0.70	2.94	3.08	3.30	3.54	3.65
EL	0.30	0.30	0.26	0.23	0.18	0.18	1.25	1.25	1.16	1.13	1.10
γ	2.04	2.17	2.66	3.20	4.60	5.30	0.60	0.78	1.03	1.28	1.36
D_{max}	1.56	1.72	1.71	1.70	1.71	1.71	1.54	2.05	2.69	3.28	3.55
DS	1.54	1.69	1.69	1.69	1.69	1.68	1.32	1.85	2.50	3.00	3.22
DI	0.59	0.68	0.68	0.70	0.86	0.93	0.68	0.94	1.20	1.44	1.48
10/*i*							320	400	440	470	530

the six contrast grades of positive material as illustrated in Fig. 6, while in the second section are analogous values for the five development times of a typical negative material as illustrated in Fig. 8. The values of exposure scale for these positive materials decrease progressively from the 0 grade, which is a relatively soft or flat material, to No. 5 which is an extremely hard or contrasty material. These values of *exposure scale* determine the *density scale* of the negative which can be rendered on the various positive materials. It should be remembered, however, that the *exposure scale* of the positive material is not the factor which limits the *object contrast* that can be rendered in the positive, this being limited rather by the *density scale* of the *positive* material. On the other hand, the *exposure scale* of a negative material is the characteristic which limits the *object contrast* which can be rendered on the *negative*, but, as will be seen from the values in Table II, negative materials have, in general, high values of exposure scale ranging in this case from 3.0 to a value

greater than 3.6. An exposure scale (logarithmic) of 3.0 is sufficient to render an object contrast of 1000, while a value of 3.6 corresponds to an object contrast of 4000. These values are much greater than the value considered to be average for the exterior scenes and, in fact, they are probably well above the greatest contrast ever encountered in such scenes.

As stated previously, the total exposure scale of a negative material has usually been expressed in terms of the log exposure distance between the points having gradients of 0.20. More recent conceptions of the conditions leading to good tone reproduction raise the question of the utility of such exposure-scale values. It seems probable that the methods of defining *useful* exposure scale should be revised. The reason for this may be illustrated by reference to Fig. 11.

FIG. 11.



Curves illustrating poor tone reproduction quality in highlight region with overexposure.

As stated previously, the negative and positive characteristics producing perfect tone reproduction must be mirror images of each other, as illustrated in Fig. 11. Three developing-out paper characteristics are shown in the lower left-hand quadrant of the tone reproduction diagram. Two of these are for contrast grade No. 1, and the third, for contrast grade No. 2. In the lower right-hand quadrant the three corresponding solid curves are the mirror images of those in the left-hand quadrant and therefore represent the D-log E characteristic

of the negative material producing perfect tone reproduction when used with the positive materials as represented. The dotted curve A represents an actually available negative characteristic which fits closely the theoretical requirement (solid curve) for the log brightness range of 1.5. If the negative exposure is increased sufficiently, using the same negative material as that represented by the dotted curve A, the brightness scale of the object will be rendered on a *straight-line* portion as represented by the dotted curve A'. By using the next less contrasty grade of developing-out paper, that is, contrast No. 1, the departures from the theoretical requirement are not very great, although somewhat greater than in the case of the characteristic curve A when used with contrast grade No. 2. The tone reproduction obtainable with the A' curve will be fair although not as good as in the case of the first example.

If the negative exposure be still further increased so that a portion of the tonal scale of the object is pushed up onto the shoulder region of the negative material, as illustrated by the dotted curve A'', a very serious loss in quality of tone reproduction is encountered. The gradient in the highlight region of the negative now begins to decrease although the theoretical requirement for perfect reproduction is an increasing gradient. In the case illustrated by the curve A'', very little can be accomplished by changing to a different contrast grade of positive material, since all of these materials have the same general shape in the toe region. The negative characteristic curve in the shoulder region has a curvature *opposite* to that which it should have, with the result that rendering of detail in the highlights deteriorates very rapidly causing serious and rapid loss of print quality.

Evidence will be given later in this paper showing that the useful part of the characteristic curve is not limited in the low density region by a point having a fixed gradient. In view of these circumstances it may be wise to abandon the practice of expressing total *useful* scale as the distance between points having fixed gradient values. A definite recommendation for an alternative method cannot be made at the present time, but it seems reasonable to assume that the useful scale is limited in both the low and high density regions by points

which have gradients which are some function of other gradient characteristics of the negative curve and of those of the positive on which the print is made. In any case it is quite certain that the gradient of the limiting point in the low density region is considerably less than that in the high density region, this conclusion being supported by the argument presented in previous paragraphs in which the curves of Fig. 11 are discussed.

VI. METHOD FOR THE DETERMINATION OF THE DEPENDENCE OF PRINT QUALITY ON NEGATIVE EXPOSURE.

The next phase of this investigation deals with direct practical tests to determine how closely perfect reproduction can be approached with available negative and positive materials and to establish if possible a correlation between magnitudes and types of departure from perfect reproduction and the print "quality" as determined by direct visual evaluation of print quality by a large group of both experienced and inexperienced judges.

The Series of Test Negatives.—The method employed is a relatively simple one and involves the making of a series of exposures on a chosen negative material to a suitable scene, the exposure being increased by known and constant increments from one resulting in an extremely underexposed negative to one giving a very fully or even overexposed negative. The exposure increment adopted for this work is approximately 40 per cent, this being equivalent to a log exposure increment of 0.15. Thus, the exposure is doubled for each alternate negative in the series. The exposed materials are then developed together in a sensitometric developing machine which insures identical development for all negatives and extremely uniform development of each negative. A development time of 5 minutes in formula DK-50 at a temperature of 65° F. was chosen as representing the average processing conditions to which amateur negative materials are generally subjected in practical work. This processing treatment yields a normal contrast, giving gamma values falling between 0.8 and 1.1, for practically all of the widely used amateur negative materials. On each negative material a series of twelve such exposures was made.

The Negative Materials.—For this work four negative materials used extensively in the amateur field were chosen. These will be designated as *A*, *B*, *C*, and *D*. They represent fairly well the range of materials used in the amateur field from the point of view of color sensitivity, speed, and shape of the *D*-log *E* characteristic. The materials actually used were taken from stock without being selected particularly as representing the average of production from the standpoint of speed. Nor were they of identical ages. Hence, any values of speed derived directly from the print judgments cannot be interpreted as representing the average of the four products as made over a period of time and at identical ages.

The Test Object.—Careful thought was given to the choice of a suitable object for use in making the series of test negatives mentioned above. The first impulse was to use as a test object an assemblage of objects in three dimensions, in other words to use some bit of natural scenery, architectural detail, a living model, a street scene, or any one of the innumerable things of which photographs are made. On further consideration, however, it appeared that a better procedure could be devised, namely, to use as a working object a transparency made under precisely known and controlled conditions. In making several series of exposures, each series consisting of a relatively large number of negatives, it is extremely difficult to be sure that the lighting conditions on an outdoor scene will remain sufficiently constant over an adequate period of time. Moreover, it may be desirable to make these series on different days and here the case of controlled and reproducible lighting is even more hopeless. With a living model, the problem of reproducibility of intensity and distribution of illumination can be solved satisfactorily by working in a studio illuminated with artificial light. Experience has shown that it is practically impossible for a living model to maintain the same pose over a sufficient period of time and even more difficult for the model to assume exactly the same pose on different occasions.

It also seemed desirable to eliminate as completely as possible from this present study effects due to color. The negative materials used in the amateur field differ markedly among themselves with respect to color sensitivity and hence

the apparent relative speeds of these materials may be profoundly influenced by the color characteristics of a particular scene. It has been shown, moreover, that *on the average* the world is gray[8] and while in many cases scenes must be reproduced in which certain colors predominate, it seems most logical to attempt to make the evaluations of the effective camera speed of negative materials in terms of the statistical average color of all scenes, namely, gray.

This discussion will be confined to the rendition of a scene having *average* contrast with a camera and lens equipment having *average* flare characteristics. The available evidence indicates that under these average conditions the ratio of maximum to minimum image illumination incident on the photographic negative material is approximately 32. It is evident that it is the brightness characteristics of the image formed on the photographic material which determines how much and what part of the negative characteristic curve is used under a specified set of conditions. If a positive transparency is to be used rather than a real three-dimensional scene, it should have characteristics such that when photographed in the copying camera the brightness contrast characteristics of the image on the negative material used in the copying camera will be identical with those incident on the negative material used in photographing the original scene.

Many negative materials are available which have exposure latitudes, EL (see page 315, and Fig. 5), greater than 32 ($\log EL = 1.50$). This is also true of materials suitable for use in making a positive transparency of the original negative. Hence, it is possible, by adjusting the exposure used in making the negative of the original scene and the contact printing exposure used in making the positive transparency, to use only the straight-line portion of both the positive and the negative materials. The processing conditions may also be adjusted so that the product of the negative gamma by the positive gamma is equal to 1.0. If such a transparency is photographed with a camera and lens equipment having no flare, the brightness distribution in the camera image of the original scene will be reproduced perfectly on the negative material in the copying camera. This condition can be approached very closely when photographing the

positive transparency because it may be surrounded by a large black field, thus eliminating to a great extent the source of flare light in photographing the original scene. Moreover, by proper design of the copying camera (including the camera body, the lens, lens mount, shutter, and diaphragm elements), flare due to these sources may be reduced to a very low value. Thus, by means of a positive transparency, the brightness distribution in the original camera image may be duplicated on the focal plane of the copying camera. It is then a simple matter to make a series of negatives, on as many different negative materials as desired, under precisely controlled and reproducible conditions. By exercising great care at every step in the process, negatives can be obtained which are practically identical with those made by photographing the original scene.

The scene chosen for this investigation is that already shown in Fig. 4, but in order to make the ratio of height to width more convenient, a part of the composition at the extreme left was eliminated without, however, altering the over-all contrast of the scene, since the sky as seen through the trees (15) has a brightness equivalent to that of the sunlit awning (14) at the extreme left. The contrast of the image illumination, I_i, on the photographic material, therefore, is given by the ratio 12.5 to 0.45, this being 28 (see Table I), which is only slightly lower than the value of 32 assumed as the average.

The original negative was made on a panchromatic material with a carefully adjusted orthochromatic corrective filter so as to obtain a rendition of the relative brightnesses of the variously colored areas of the scene corresponding as closely as possible to the visual evaluation of those brightnesses. The exposure was adjusted so that the entire tonal scale of the camera image was rendered on the straight-line portion of the negative characteristic. The average of the photographic-photometric measurements made on ten different negatives was used in establishing the over-all image contrast of 28 (log brightness scale of image, BS_i, is equal to 1.45). The exposure used in making the transparency (printed by contact) was also adjusted so only the straight-line portion of the positive material was used. The exposed

FIG. 12.

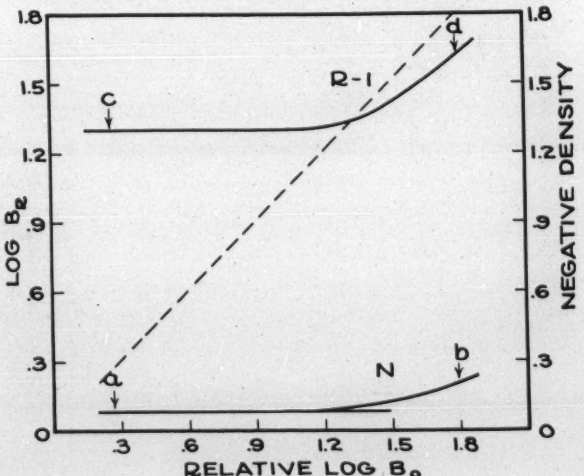
Reproduction of transparency test object carrying graded density scales.

positive material was then developed to such an extent that a density scale, DS_p, of 1.51 was obtained for the resultant positive transparency. In this way the brightness contrast of the transparency is raised to 32, which has been assumed

FIG. 13.

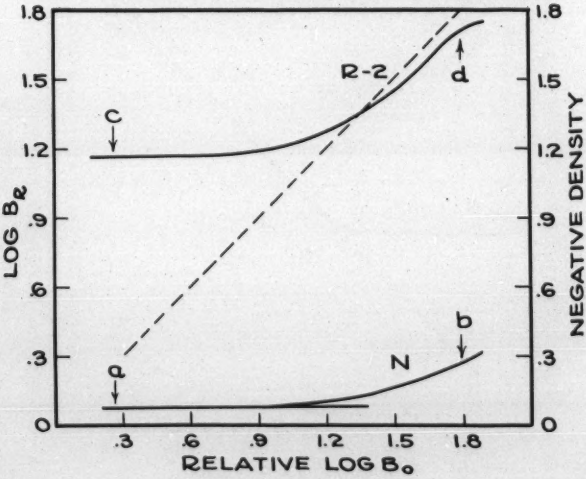
Reproduction of prints obtained by varying the printing time and the contrast grade of paper.

FIG. 14.



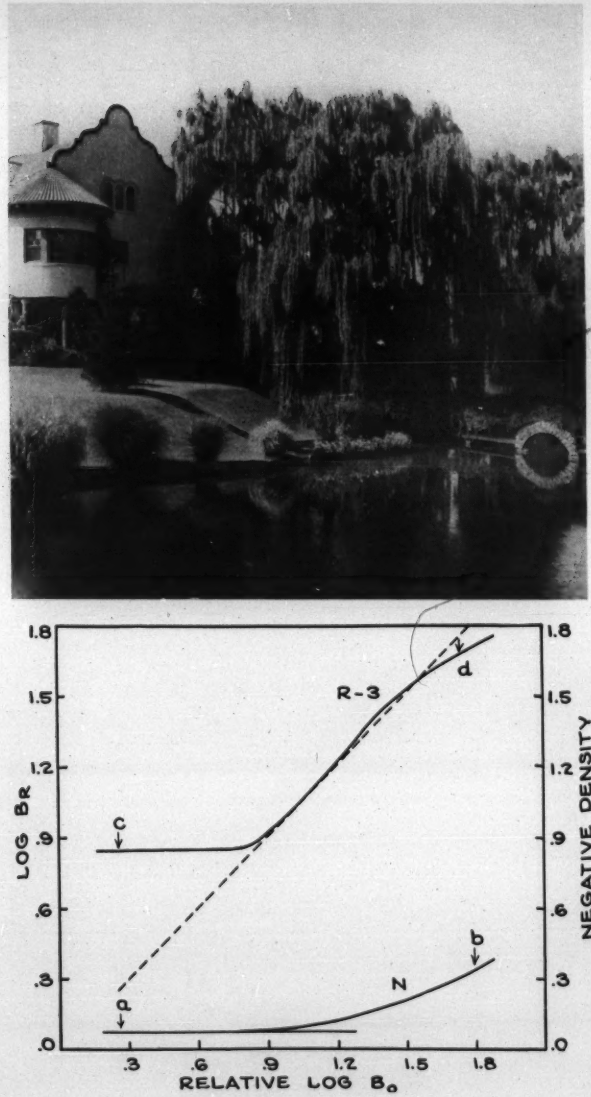
Characteristic curve for negative No. 1 (curve *N*) and the reproduction curve (*R*–1) for the best possible print made therefrom.

FIG. 15.



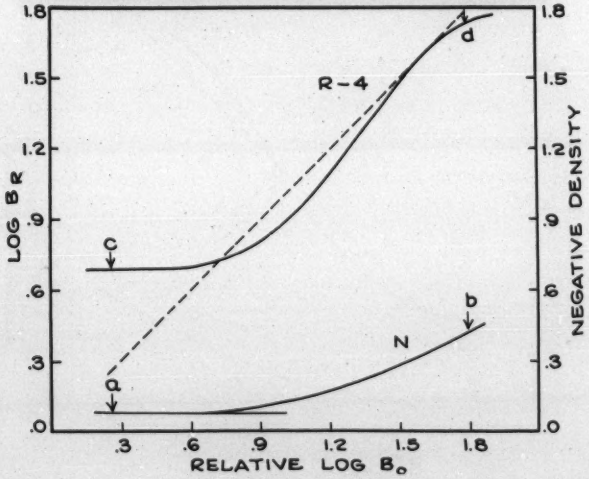
Characteristic curve for negative No. 2 (curve *N*) and the reproduction curve (*R*–2) for the best possible print made therefrom.

FIG. 16.



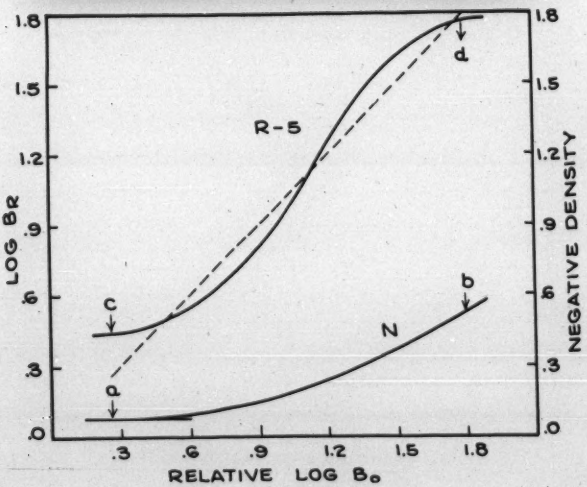
Characteristic curve for negative No. 3 (curve *N*) and the reproduction curve (*R*–3) for the best possible print made therefrom.

FIG. 17.



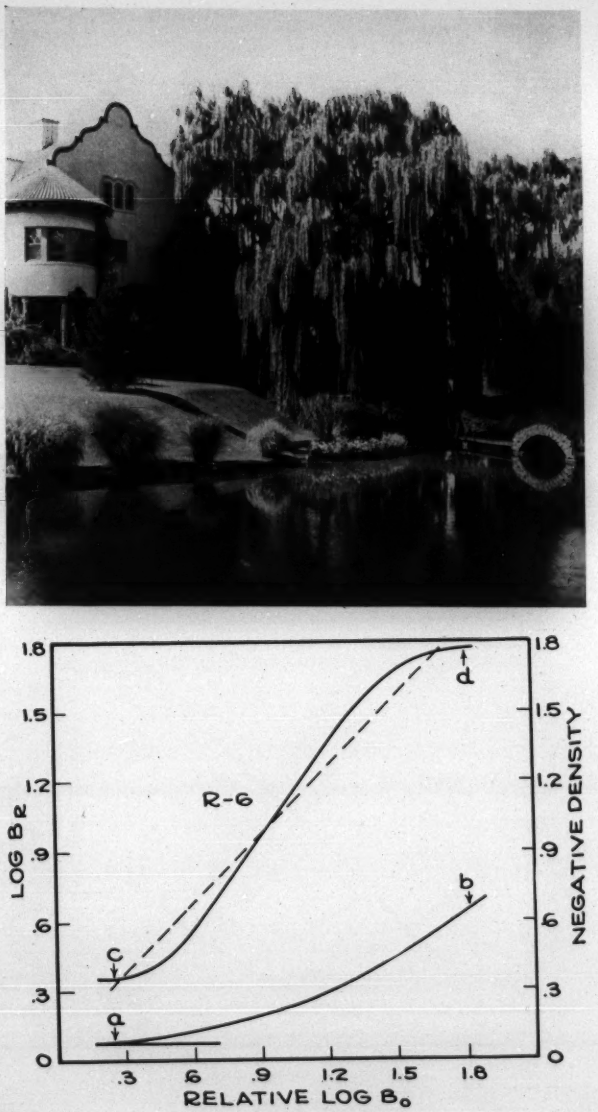
Characteristic curve for negative No. 4 (curve *N*) and the reproduction curve (*R*-4) for the best possible print made therefrom.

FIG. 18.



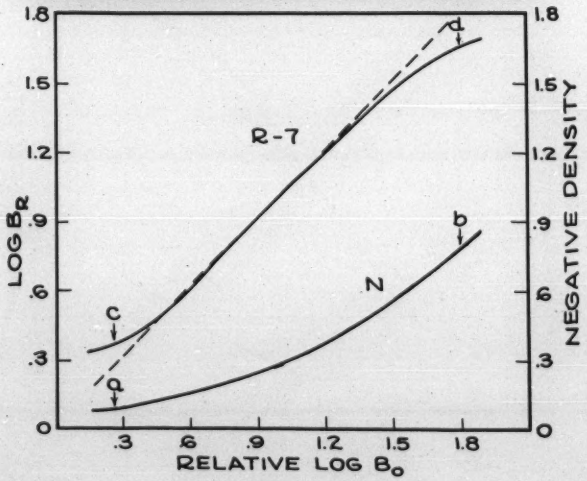
Characteristic curve for negative No. 5 (curve *N*) and the reproduction curve (*R*–5) for the best possible print made therefrom.

FIG. 19.



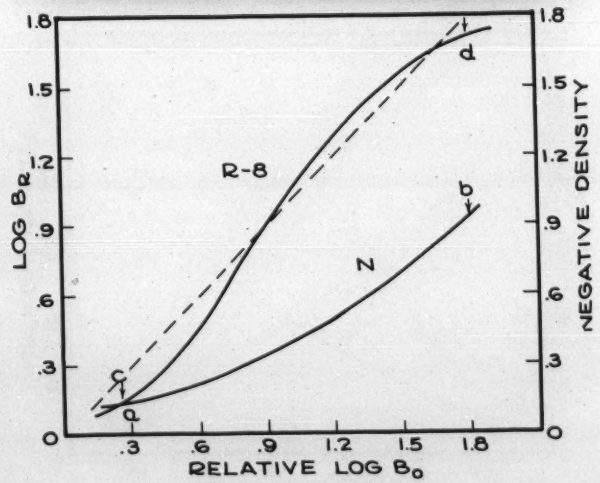
Characteristic curve for negative No. 6 (curve *N*) and the reproduction curve (*R*–6) for the best possible print made therefrom.

FIG. 20.



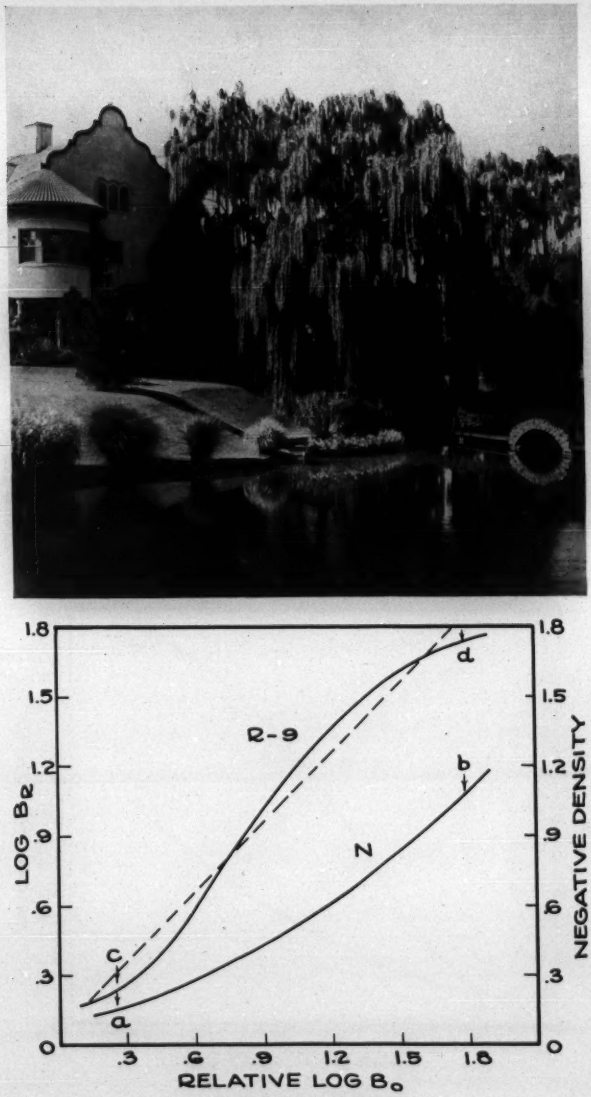
Characteristic curve for negative No. 7 (curve *N*) and the reproduction curve (*R*–7) for the best possible print made therefrom.

FIG. 21.



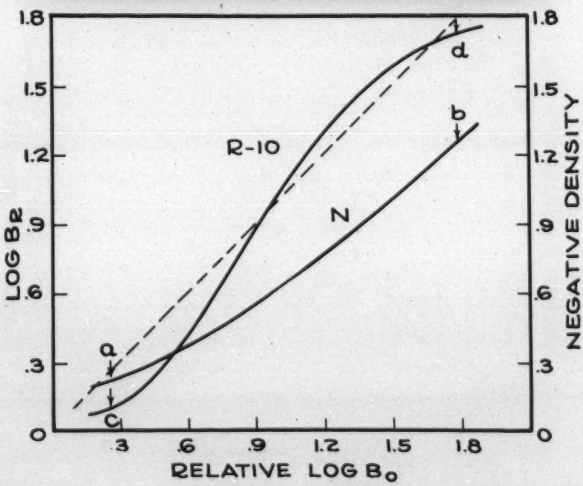
Characteristic curve for negative No. 8 (curve *N*) and the reproduction curve (*R*–8) for the best possible print made therefrom.

FIG. 22.



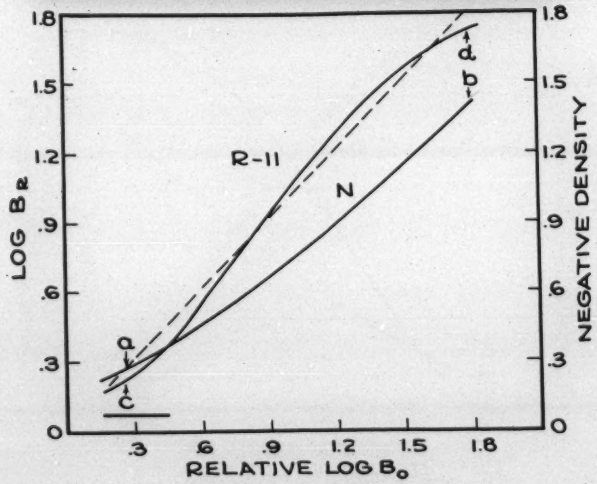
Characteristic curve for negative No. 9 (curve *N*) and the reproduction curve (*R*–9) for the best possible print made therefrom.

FIG. 23.



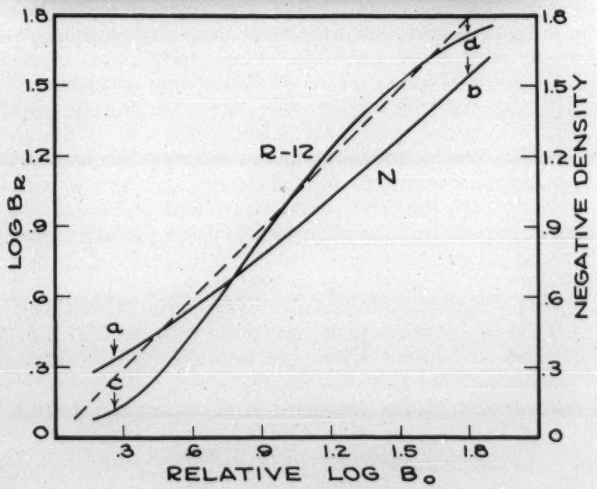
Characteristic curve for negative No. 10 (curve *N*) and the reproduction curve (*R*–10) for the best possible print made therefrom.

FIG. 24.



Characteristic curve for negative No. 11 (curve *N*) and the reproduction curve (*R*–11) for the best possible print made therefrom.

FIG. 25.



Characteristic curve for negative No. 12 (curve *N*) and the reproduction curve (*R*-12) for the best possible print made therefrom.

as a reasonable value for the average image illumination contrast. A reproduction of the final transparency is shown in Fig. 12. It will be seen that neutral gray scales were mounted at the top and bottom of the picture areas. These are used in making measurements for the computation of tone reproduction quality. Prints from the picture area only are used in the determination of reproduction quality by direct judgment.

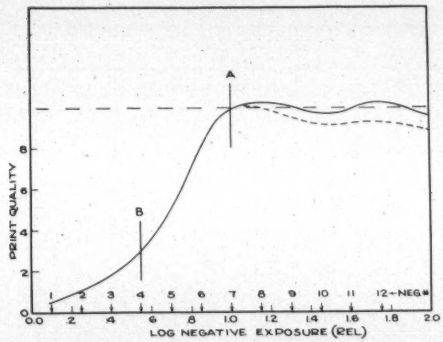
Series of Prints.—Having obtained a series of test negatives for each of the four negative materials, prints were made therefrom. Those responsible for making these prints were instructed to make the best possible print from each negative by using any one of the six contrast grades of developing-out papers as illustrated in Fig. 6. In order to do this, it was, of course, necessary to make a series of prints, in which the printing exposure was varied on each of two or three of the contrast grades available. Such a set of prints is illustrated in Fig. 13. The prints in the left-hand column were made on No. 1 contrast, the variation in the vertical direction being printing exposure. Likewise, those in the center column were made on the No. 2 grade, while those in the right-hand column were made on the No. 3 grade, the variable in the vertical direction being exposure. All of these prints were developed for a fixed recommended time in the developer recommended for use with these materials. From each group of such prints, one was chosen as being the best that could be made from that negative with any variation of printing paper contrast and printing exposure. In this way a series of twelve prints was obtained for each of the four negative materials. Reproductions of the twelve prints obtained from negative material *C*, the *D*-log *E* characteristics of which have already been shown in Fig. 8, are shown in the upper parts of Figs. 14 to 25 inclusive.

VII. QUALITATIVE RELATION BETWEEN NEGATIVE EXPOSURE AND PRINT QUALITY.

If the twelve prints of any one of these series (Figs. 14–25 inclusive) are laid out adjacent to each other in a horizontal row with the print from the negative which had received the least exposure at the extreme left of the series, a casual

inspection shows at once that the photographic quality at the extreme left is very poor and that the quality improves step by step to the right, finally reaching a point beyond which there is *little, if any*, further improvement. This relationship between negative exposure and quality can be illustrated approximately by the curve of Fig. 26. Individual estimates of the shape of this curve may vary slightly, but there is no doubt that its general form will be agreed to by all observers and, in fact, the solid curve shown in Fig. 26

FIG. 26.



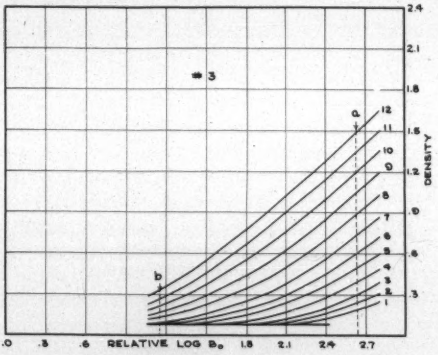
Curve showing the approximate relationship between print quality and negative exposure.

represents the consensus of opinion of several observers. According to this it appears that the quality improves somewhat slowly for the first two or three prints (to the left of the point designated by *B*), then quite rapidly (to the point designated by *A*), after which the change in print quality is relatively small and somewhat uncertain in sign. In the region to the right of *A* there is considerable disagreement among observers as to whether the general tendency is somewhat upward or somewhat downward, or possibly oscillating about a horizontal line, as indicated by the solid curve. While there may be some doubt as to the *exact* shape of this function, there is no doubt whatever as to its *general* shape.

VIII. PRINT QUALITY IN TERMS OF THEORETICAL TONE REPRODUCTION.

Referring again to Fig. 12, it will be seen that intensity-scale stepped exposures were impressed on each negative. From these the effective operating D-log E characteristics as obtained in the camera can be plotted. These are shown in Fig. 27 for the twelve negatives made on the negative material C. Vertical lines drawn through the points a and b show the limits of the test object brightness range. The portions of the curves lying between the vertical dotted lines at these points therefore represent the parts of the characteristic actually used in reproducing the test object.

FIG. 27.

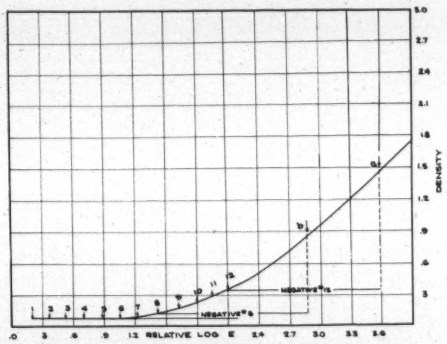


D-log E characteristics of twelve negatives made on material C.

By displacing the *partial* curves of Fig. 27 laterally, the *complete* D-log E characteristic can be constructed. This is shown in Fig. 28. This is the effective operating characteristic for this negative material (C) as determined under the same camera conditions as those existing in making the test negatives. The points 1 to 12 indicate the points at which the minimum test object brightness (extreme object shadow) was rendered in the various negatives. It will be seen from this figure, that in the case of negative No. 1, a rather large

percentage of the entire tonal scale of the test object was rendered on a part of the characteristic curve having zero gradient, the remainder of the tonal range being rendered on the extreme toe. As negative exposure was increased, more and more of the tonal range is rendered by a part of the curve having finite positive gradient until in the case of No. 12 the major portion of the tonal range is rendered on the straight-line region. Negative exposure was not increased

FIG. 28.



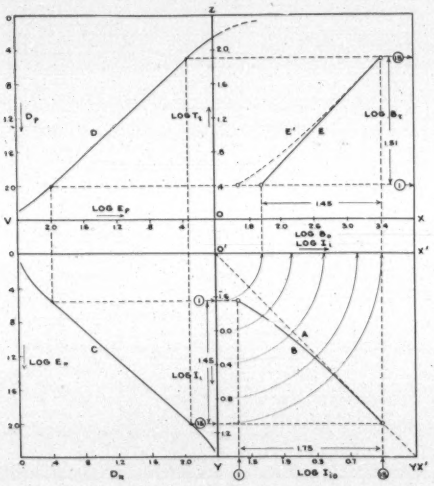
The *D*-log *E* characteristic of material *C* constructed from the twelve partial characteristics shown in Fig. 27.

sufficiently to push the highlights of the test object into the shoulder region.

The graded step densities at the top and bottom of the test negatives were of course reproduced in the prints. Reflection densities of these areas were read, and when combined with the corresponding densities of the negative permitted plotting the effective operating *D*-log *E* characteristics of the positive material for those conditions under which it was used. Using these *D*-log *E* characteristics of the negative and positive materials, it is now possible to plot the theoretical tone reproduction curve for each print. This was done and in the lower parts of Figs. 14 to 25, inclusive, the results are

shown for the prints derived from the series of negatives made on material *C*. The curve designated as *N* represents the *D*-log *E* characteristic of the negative. The curve *R* is the computed tone reproduction curve. The dotted straight line at 45 degrees to the log *E* axis is the curve of perfect tone reproduction. Points *a* and *b* represent minimum and maximum negative density, respectively, while points *c*

FIG. 29.



Tone reproduction diagram illustrating the method of constructing the tone reproduction curves shown in Figs. 14 to 25, inclusive.

and *d* represent maximum and minimum print densities, respectively.

Attention should be called at this point to the relation between the brightness scale of the original scene and that of the positive transparency, and to the way in which the tone reproduction curves are constructed. This can be illustrated by reference to Fig. 29. In the lower right-hand quadrant

is plotted the flare curve for the camera and lens system as used in making the original negative. This shows the relationship between the total image illumination, I_i, and that part of the image illumination, I_{io}, which comes from the object. The values of I_{io} are therefore those which would have been obtained had there been no flare light present. If the flare illumination in the image be designated by I_{if}, then the three quantities are related by the expression:

$$I_{io} = I_i - I_{if}.$$

On the line $O'Y$ is established a logarithmic scale on which may be plotted values of total image illumination, I_i. Points designated as 1 and 15 show the limits of this image illumination scale, these values being taken from the third column, $\log I_i$, in Table I. On the line Y, YX' is established a logarithmic scale on which may be plotted values of I_{io}.

By *flare light* is meant the non-image-forming illumination which is uniformly distributed over the surface of the sensitive material as distinguished from *flare spots* where the distribution is not uniform. In this case measurements show that the flare illumination, I_{if}, had a value of 0.23 meter candle. Thus, it is possible to plot on the $\log I_{io}$ scale points corresponding to selected points on the $\log I_i$ scale. Verticals and horizontals drawn through these points establish by their intersections the position of the *flare curve B*. It will be seen that the presence of the flare is responsible for a shortening of the image illumination scale from 1.75 to 1.45.* It will be

* The information previously published [9] on the brightness distribution in this subject was subsequently found to be somewhat in error because of the presence of stray light in the portable photometer with which the brightness measurements were made. By direct comparison with an instrument which is free from this trouble, the amount of this stray light has been determined. Applying this correction gives an over-all object brightness contrast of 56 rather than 39, as reported previously. By using a value of 0.23 meter candle for the flare light present in the camera when making the original negatives and the photographically determined values of image illumination (I_i, Table I), the value of I_{io} shown in Table I were computed. From the known characteristics of the image-forming system, the ratio of object brightness, B_o, (foot lamberts) to image illumination, I_{io}, (meter candles) was found to be 204. Thus, values of photographic object brightness, B_o (p), as shown in the last column of Table I were computed. These

seen also that the compression of illumination differences is most marked in the extreme shadow region, but even here the slope of the flare curve is not greatly less than 1.0 which is obtained when the flare illumination is zero. By swinging the points on the $O'Y$ axis about the point O' as a center, they may be transferred to the $O'X'$ axis, which is also a logarithmic scale of image illumination, I_i. They are now in position to use in constructing the tone reproduction curve for the transparency.

In the lower left-hand quadrant is plotted the characteristic curve of the material on which the positive transparency was made. It should be noted that this curve is upside down and reversed from right to left as compared with the usual method of plotting this characteristic. Carrying through the tone reproduction construction in the usual manner, the curve E in the upper right-hand quadrant is obtained. It should be emphasized that this represents the tone reproduction relationship between the brightness values in the transparency and the image illumination rather than the object brightnesses.

The fact that E is a straight line means that, by using a transparency made in the manner previously described, a directly proportional reproduction of the brightness distribution incident on the original negative material is obtained on the negative materials exposed in the copying camera. The contrast in the transparency between maximum and minimum brightness is now 32 (the assumed average for image illumination contrast) and it is upon this scale that the tone reproduction curves in Figs. 14 to 25 are constructed.

If a tone reproduction curve is to indicate to what extent the given negative and positive materials are capable of correctly reproducing a tonal scale, it should be plotted in this manner

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of course cannot be expected to agree perfectly with values measured visually because of the presence of some color in the scene. However, the highest light, point 15, was the white hazy sky just above the horizon, and the deepest shadow, point 1, was the dark gray (practically neutral) tree trunk, and it is considered that the over-all contrast, as determined by photographic photometry, should be essentially the same as the over-all contrast as measured visually. The values at the bottom of Table I show the over-all contrast of the various factors expressed arithmetically and logarithmically.

in order to eliminate apparent distortion attributable to camera flare rather than to the failure of the negative and positive materials to reproduce brightness differences correctly. Since, in the evaluation of the effective camera speeds by a sensitometric method, it is of major importance to determine the characteristics of the part of the negative curve which is used in obtaining some specified print quality (such as "first excellent" or "just acceptable"), it seems most logical to construct the tone reproduction curve on the image brightness scale.

On the other hand, it might be assumed that in an attempt to obtain a correlation between the characteristics of a reproduction curve and direct statistical judgments of print quality, the tone reproduction curve should be constructed on the basis of the object brightnesses and brightness differences. This assumption is valid, however, only if the purely objective quality of tone reproduction is being considered. Since the quality value assigned to a given print by direct judgment is most certainly determined by subjective as well as objective factors, it is questionable whether an objective reproduction curve is of maximum significance. For instance, if a scene has a very high ratio of maximum to minimum brightness, it is almost certain that a tone reproduction curve plotted on a base line covering the entire objective brightness scale will yield less information on the print quality than when the tone reproduction curve covers only that part of the objective brightness scale lying between "subjective black" and "subjective white." While it is true that a reproduction which is *perfect* from the objective standpoint should, when viewed under similar conditions, reproduce precisely the impression in the observer's mind when viewing the original, such a condition is not *necessary* for perfect reproduction of the visual impression. The case is somewhat similar to one encountered in the field of color. Two colored surfaces will appear identical in case the spectral compositions of the light reflected therefrom are the same. It is not necessary, however, that the spectral compositions be identical, for the same impression may be produced by spectral compositions differing appreciably from each other. Likewise, perfect

objective reproduction may be unnecessary for perfect reproduction of the subjective impression.

In the case of the particular scene being used in this investigation, there was no appreciable difference between the "blackness" of points 1 and 3, although a photometric measurement showed 1 to be of appreciably lower brightness than 3. If there are brightness differences below that which may be called "subjective black," there is no particular virtue in reproducing them in the reproduction since they were not visible in the original. Hence, it would seem that a reproduction curve to be of greatest significance in evaluating print quality should be constructed on a base line which embraces all *discriminable* brightness differences rather than all actually *measurable* brightness differences. While there is some uncertainty as to the length of this discriminable brightness scale in the scene under consideration, it seems probable that the reproduction curves plotted on the basis of the image illumination value should come as close, or perhaps closer, to fulfilling the desired condition than reproduction curves plotted on the base line of total measured brightness scale. It seems satisfactory, therefore, to use the reproduction curves as shown in Figs. 14 to 25, inclusive (and similar ones for other photographic materials), for the establishment of correlations between sensitometric characteristics, camera speeds, and print quality.

If for any reason it is desirable to construct the tone reproduction curves on the basis of the total measured brightness scale, this can be done quite simply by including in the tone reproduction computations the flare characteristics as contained in curve *B* (Fig. 29).

The characteristics of these negatives, prints, and tone reproduction curves will now be discussed in some detail.

The tone reproduction curve for each print is reproduced directly below the print in question to facilitate easy comparison of characteristics. Unfortunately, it does not seem feasible to attempt to reproduce the appearance of the corresponding negatives. It is doubtful whether any satisfactory judgment of the quality of the print can be made from the half-tone reproduction thereof. An attempt will

be made to convey an idea of the appearance of the negatives by verbal description.

No. 1. The negative is extremely thin and shows no visible detail in the extreme shadow and half-tone regions. The print is extremely poor. The reproduction curve indicates no differentiation in detail for the major portion of the tonal scale.

No. 2. The negative is beginning to show a little detail in the half-tone region but none in the shadows. The print is very bad and the reproduction curve flat through at least one-half of the brightness scale.

No. 3. This negative shows fairly good detail in the highlight region, vestiges of detail in the half-tones, but practically none in the shadow region. The print shows considerable improvement as compared with No. 2. No detail is visible in the shadows. This condition is substantiated by the fact that the tone reproduction curve still shows zero gradient in this region.

No. 4. No detail is visible in the shadow regions of the negative. Throughout the half-tone region detail is appearing. In the print, detail in the shadows is just beginning to appear. This point is interesting because no detail can be seen in the negative areas representing these regions. The explanation is simple. From information relative to the visual sensitivity to brightness differences, it is known that a density difference of 0.007 is just visible under good viewing conditions. The extreme toe of the negative characteristic is printed on a portion of the positive material characteristic curve having a gradient of about 4.4; hence, a density difference in the negative of 0.002, which is quite invisible to the human eye, will be rendered in the print by a density difference of 0.008, which is slightly above the threshold. This illustrates the futility of attempting to predict print quality from an inspection of a negative. When using positive materials having a high gradient, details may appear in the print which cannot be seen in the negative.

No. 5. This negative begins to exhibit some aspects of good quality although it still appears thin with no visible detail in the extreme shadows. The print which was made

on a No. 4 grade of paper is only fair, but again shows more detail in the shadow regions than can be seen in the negative. The tone reproduction curve is beginning to approximate more closely a straight line. Gradient errors in the shadow and highlight regions are still quite high, agreeing well with the direct judgment of rather poor rendering of shadow and highlight detail.

No. 6. Detail in the extreme shadow region of the negative now makes its first appearance although the contrast does not begin to approach that in the object. The print is moderately good, considerable detail being visible in the shadows, while quality through the range of middle tones is quite good. The print as a whole, however, still lacks the earmarks of really good quality.

No. 7. The negative appears to carry detail throughout the entire tonal scale although that in the shadows and lower half-tones is obviously much below the contrast in the corresponding regions of the test object. The print here is quite good. The shadow detail appears to approach quite closely to good reproduction. The rendition of the foliage is excellent; lawn, shrubbery, water, etc., all appear natural, and, in fact, the print must be considered as fairly good, although somewhat "soft" and lacking in good "blacks." The tone reproduction curve throughout a considerable portion of its length has a slope of 1.0, and the gradient errors at the extremes are relatively small.

No. 8. The negative now beings to exhibit considerable body. Extreme shadows are represented by appreciable densities and, on the whole, the negative would be judged good. The print is good but appears slightly soft and lacking in brilliance.

The best print from this negative was made on the No. 3 grade of paper, while the best print from the No. 7 negative was made on the No. 4 grade. The lack of brilliance probably follows because of the necessity of shifting from the No. 4 to the No. 3 grade of paper. Had a grade of paper midway between No. 3 and No. 4 been available, it seems probable that the No. 8 print quality would have been a little better than that of No. 7. The tone reproduction curve shows

appreciably greater gradient errors than in the case of No. 7. This is particularly true when the gradient error is evaluated in terms of the average error over the entire tonal scale.

It might be mentioned at this point that the necessity of shifting from one grade of printing paper to another is responsible for what appears to be slight discontinuity in the trend of print quality as negative exposure is increased. In some cases it is obvious that one grade of paper is slightly too contrasty, and the next grade is slightly too soft to give the best possible print. In attempting to evaluate the relation between negative exposure and print quality, this should always be kept in mind.

Nos. 9, 10, 11, and 12. It is difficult to detect much variation in the quality of these four negatives, although, of course, average negative density increases throughout the group. Prints from negatives 9 and 10 show very good quality, these negatives being printed on the No. 3 contrast paper. It was necessary to change to contrast grade No. 2 to obtain the best prints from negatives 11 and 12. Both prints show excellent quality with No. 12 possibly slightly superior.

It appears, therefore, that the first print that can be referred to as "good" was made from the No. 7 negative and from this point on it is difficult to be sure of much increase in quality. As will be shown later, individuals differ enormously in their opinions of the sequence in which these prints should be placed on the quality scale.

Inspection of the tone reproduction curves for these four prints shows a general correlation between the magnitude of the gradient errors and the direct subjective judgment of print quality. Of the four prints, the average gradient error is least for No. 11 and, moreover, the gradient errors have a more even distribution, both with respect to positive and negative values and with respect to the occurrence of these errors in highlight and shadow regions. The evaluation of print quality in terms of gradient errors will be discussed in greater detail later.

The results of this inspection may be summarized as follows: As negative exposure is increased progressively by

equal steps from a very low value, the quality of the resultant print increases progressively. This increase, as judged subjectively, appears to be relatively slow at first and then rises at an appreciably more rapid rate to a point beyond which further increase of negative exposure gives little, if any, improvement in print quality. There seem to be some irregularities in this region of high quality which can be attributed to the fact that positive material characteristics change in steps. If, for instance, instead of having available four grades of paper contrast, there had been a larger number within the same contrast range, some of these apparent irregularities in the quality curve probably would have disappeared. However, the results of this analysis are quite conclusive and of considerable significance, especially when they are interpreted in terms of the sensitometric characteristics of the positive and negative materials and tone reproduction theory.

Examination of the series of prints made on the three other negative materials leads to the same or similar conclusions.

(*To be continued.*)

PRINCIPLES OF ROTARY AIRCRAFT.*

BY

ALEXANDER KLEMIN, M.S., LL.D.,

Professor of Aeronautical Engineering,
New York University.

(*Concluded.*)

8. Typical Autogiros and their Specifications.

Nothing illustrates the progress of an art better than a series of photographs presented in chronological order.

Fig. III-17 shows an early Cierva Autogiro, built in England by the A. V. Roe Company 1926. It will be noted subsequently what great progress has been made in trimness and aerodynamic cleanness.

Fig. III-18 shows a particularly historic Cierva C-8 with a Wright Whirlwind motor of 325 hp. It was brought over to this country by Harold F. Pitcairn, and thanks to his generosity is now a permanent exhibit at the Smithsonian Institution, on whose lawn it is seen landing.

Credit for American development of the Giro is due to the Autogiro Corporation of America and its licenses of the Pitcairn Autogiro Corporation, and the Kellett Autogiro Corporation. If we have chosen a series of Kellett machines to show chronological development, this is merely because chronological information was first secured from the Kellett Company.

Model K-2, 1932.

This is one of the first machines built by Kellett and Fig. III-19 shows a view from above. With a 165 hp. Continental engine, overall length 19 ft. 6 inches, rotor diameter 41 ft., wing width overall 26 ft., height 12 ft. 4 in., two-place, side-by-side seating, the machine had a maximum speed of 100 m.p.h., cruising speed of 80 m.p.h. and a useful load of 644 lbs.

It will be noted that four blades were employed, with a rather large solidity ratio. The rotor was mounted on an

* Presented at a meeting held Thursday, October 27, 1938.

exposed strut system, and bracing from the top of the rotor to the blades (to prevent excessive drooping of the blades) and interblade bracing gave an appreciable parasite resistance which at that time was regarded as unavoidable. Since there was no direct control a fixed wing was also considered neces-

FIG. III-17.

A 1926 La Cierva giro built in England.

sary with conventional ailerons extending over the major part of the wing span. For the same reasons conventional airplane tail surfaces were employed with low vertical tail surfaces to avoid conflict with blades in their lowest position. Again without direct control, and ailerons weakened in low speed functioning, it was considered necessary to use an extremely

wide landing gear, with the fixed wing providing a logical point of attachment for the wheels.

Model K-4, 1934.

This machine shown in Fig. III-20 had a larger engine and higher speeds than the 1932 model. The mounting of the

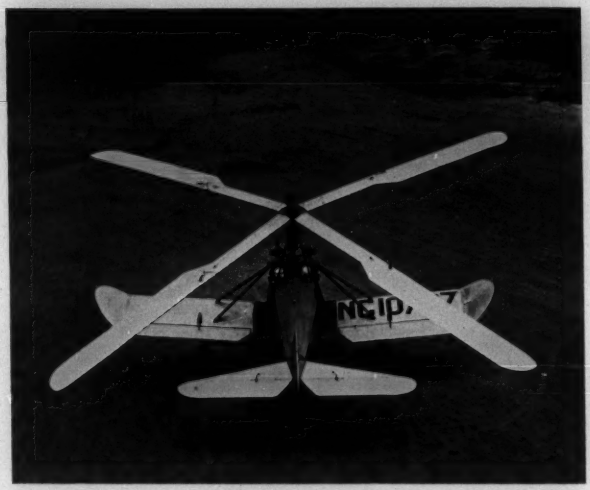
FIG. III-18.

First autogiro in America.

rotor hub is now cleaner, the wing is tapered following airplane practice, but there has been little modification in general. With a gross weight of 2400 lbs., useful load 750 lbs., 210 hp. Kinner engine, cruising speed was 94 m.p.h. With a rotor diameter of 40.6 ft., the disk area was 1295 sq. ft. and the blade area 120 sq. ft., so that the solidity ratio (blade area/disk

area) was nearly 10 per cent. The fixed wing had an area of 63 sq. ft. Climb take-off and landing run were probably close to those of the intermediate model K-3, for which figures given are: initial rate of climb 1000 ft. per min; take-off in still air, 165 ft., landing 35 ft. 7 in.

FIG. III-19.



Kellett machine of 1932.

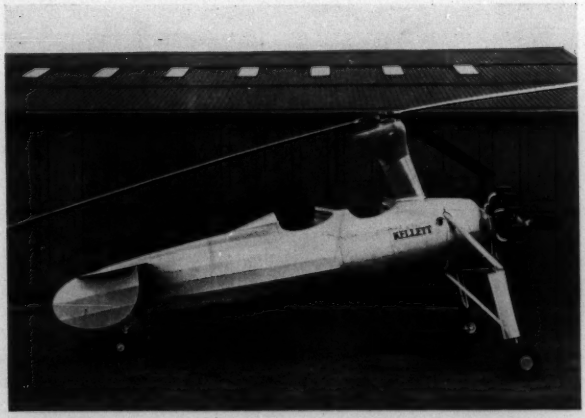
Model KD-1, 1935.

The KD-1 as indicated by the introduction of the letter D is direct control machine built by Kellett's, and now significant changes appear. The rotor diameter has only changed a few inches to 40 ft. but only three blades are employed and the solidity ratio has gone down to .045. This decrease in the solidity ratio, as previously stated, indicates that designers find higher speeds attainable with a lesser solidity ratio combined with little effect on the landing and take-off characteristics. Thanks to the direct control, elevator, rudder and ailerons have disappeared and only small stabilizing

FIG. III-20.

Kellett machine of 1934.

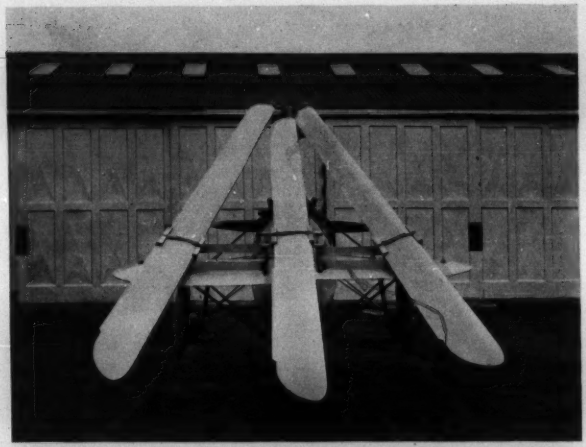
FIG. III-21.



One of the first direct control machines, 1936.

surfaces remain. With horizontal tail area of 22 sq. ft., and vertical tail area of 12 sq. ft. all external wiring from rotor to blades, or between blades has disappeared, showing that designers have learned how to prevent excessive flapping motion and excessive relative motion in the plane of rotation without parasite resistance-producing elements. All rotor controls and mountings have disappeared within a single

FIG. III-22.



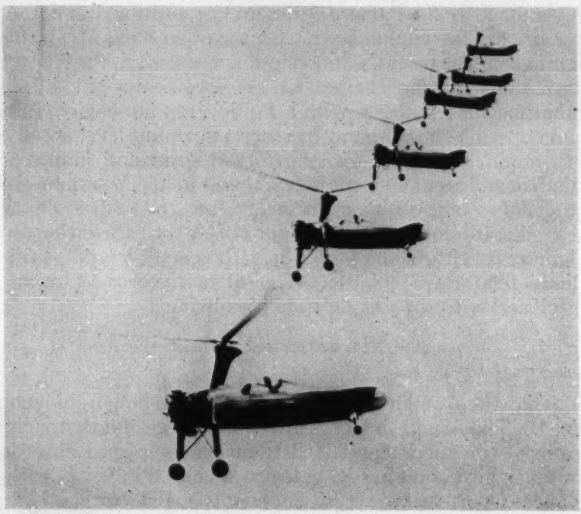
Folding back the blades of a direct control giro.

streamline mast. The resistance or drag of the rotor has been decreased by decrease of the solidity ratio, and by better plan form of blades. Gross weight has gone down to 2,075 lbs. while the useful load has increased to 700 lbs. with a 225 hp. Jacobs' engine, the quite respectable high speed of 125 m.p.h. is listed. Thanks to a lower hp. loading and greater efficiency, and the low stall speed, take-off is only 60 feet. With the direct control remaining efficacious, the landing run is correctly given as nil, though this presupposes of course a special technique. The minimum speed in level flight has

attained the extraordinary low value of 16 m.p.h. The equipment and accessories compare favorably with the test airplane practice.

The KD-1 Sport Commercial is nicely illustrated in Fig. III-21. In Fig. III-22 we see a rear view of this machine with wings folded back, a rapid process entailing the manipu-

FIG. III-23.



A military flight in echelon.

lation of a few hinge pins, and an obvious inducement to build a roadable autogiro.

It will be noted that even with the advent of direct control, the width of tread of the landing gear remains somewhat greater than in the airplane. Also to take up the somewhat greater velocities in steep landings, the giros have retained a larger oleo shock absorber travel.

The photograph of Fig. III-23 shows six YG-1 B Kellett machines, of substantially the same characteristics as the

KD-1, in echelon flight with six machines manned by Army Air Corps pilots—an ocular demonstration of the fact the giro has a definite place in military work. The YG-1 B with the same 225 hp. Jacobs' engine has a maximum speed of 130 m.p.h. and a useful load of 855 pounds.

Specification of a Forthcoming Hafner Gyro.

It is an open secret that some remarkable advances are now being made by the Pitcairn Autogiro Corporation, but nothing definite has been announced. On the other hand Mr. Hafner in England has recently announced a new design, the AR 4, to have the following characteristics: Two seater side-by-side cabin machine powered with a Pobjoy 125 hp. engine, minimum speed 18 m.p.h. and to reach maximum level speed of 115 m.p.h. Take-off with no forward run and immediate climb in still air at an angle of less than 1 in 3. Minimum area needed for take-off to measure 25 feet by 12 feet on the ground, with 40 feet clearance for the rotor. Obstacle 50 ft. high to be cleared in 50 yards. Range 2½ hours. Initial climb 1000 ft. a minute. The attractiveness of such a specification to the private owner is obvious.

9. Achievements to Date and Immediate Developments.

Military Utility of the Autogiro.

That the Autogiro has military utility is now fully recognized. The Army Air Corps after purchasing and thoroughly testing two experimental Kellett machines, placed an order for seven giros, and has an autogiro squadron in being, whose service reports have been eminently satisfactory. Many thoughtful scholars of national defense have voiced the opinion that the military autogiro has a definite sphere of usefulness. Brigadier General McNair has stated that the giros have flying characteristics, such as minimum speed of 16 miles per hour, the ability to hover above a selected point when flying with a moderate wind, landing in a very restricted spot, almost vertical descent with or without power, adequate speed, and jump take-off, which have a special appeal for the artilleryman. In fact the General is of the opinion that a rapid, detailed reconnaissance by gyro can be made more effectively than by any other means, either air or ground. For many types of

military observation it is a serious competitor of the airplane, and certainly threatens to displace the vulnerable observation balloon, whether captive or motorized. It is true that the military airplane has greater speed and effective gun power, but the giro is less visible in the air, and offers better sustained vision to its crew. Many infantry officers hold similar views, and there is not the slightest doubt that the autogiro is now and will remain a valuable tactical element for the Army Air Corps.

Safety Record.

While the autogiro has frequently encountered minor accidents in the hands of private owners, particularly in regard to the rotating blades, it has an extraordinary safety record with but three or four fatal accidents on record in its many years of flying in all civilized countries of the world. Its ability to make use of a small plot of ground for landing, its slow and almost vertical rate of descent, its complete freedom from stalling, spinning or loss of control at low speed, its practical immunity to the effects of engine failure, render it perhaps the safest of all heavier-than-air craft essayed to date.

Achievement in Flight Qualities.

Perhaps the general achievements of the autogiro as a flying machine may be summarized as follows: perfect landing and take-off characteristics; wonderful maneuverability; control under all conditions, including the slowest speed; perfect ease always; and moderate top speed.

The autogiro can descend vertically within close distance of the ground, flatten out into a short steep glide and "squat" down on the ground with practically no landing run. With the direct take-off it abolishes the take-off run and comes close to the ideal of the helicopter. With the direct control it has this enormous advantage over the airplane that the control power does not diminish with low speed, as is the case with the ailerons and elevators, whose power depends for a given displacement on the speed of the airstream. Since the rotor recognizes no side slip, and since the stall point is almost nonexistent, the giro can safely be made to perform the sharpest turns, and its normal maneuverability far exceeds that of

any airplane, even though it cannot aspire to aerial acrobatics.

The autogiro has to fear neither stall nor spin, with its ever-spinning rotor. And its high speed, cruising speed and load carrying capacity for a given horse-power are adequate for private flying and for many other purposes.

These flying characteristics fully explain the feeling of perfect ease which one feels when aloft in a giro. The writer will never forget the remarkable sensation of flying behind Harold Pitcairn from his country house to his factory, hedge

FIG. III-24.

Landing on the roof of the Philadelphia post office.

hopping all the way, with not the slightest concern on the part of either pilot or passenger, a trip which Mr. Pitcairn at one time made almost daily. Many a veteran airplane pilot flying low over a golf course in a giro has had to confess that never has he been so free from anxiety, never so forgetful of the necessity of keeping a landing field in view.

These flying characteristics also fully explain the many striking achievements which have so impressed themselves on our minds, such as landing on the White House lawn, or

bringing in mail on to the roof of the Philadelphia Post Office (see Fig. III-24). They explain also why so many industrial uses have been found for the autogiro, as in photography, insect spraying, forest patrol, etc., why ferry service to airports would be such a promising application, and why private owners have purchased the relatively expensive and slow autogiro with such eagerness and invariably speak of their craft with so much sincere admiration. And although Harold Pitcairn and his associates have preferred to concentrate on development and research, almost 200 giros have been sold to the American public.

Immediate Developments.

We have stated previously that the death of La Cierva was no bar to future progress. Harold Pitcairn, and his chief engineer, Agnew Larsen, are busily at work and the hearings on the Dorsey Bill before the House Military Affairs Committee have disclosed that they expect to have completed in the very near future some highly remarkable improvements in the rotor hub design. Efforts required to control the rotor directly have proved heavy on occasion. Air bumps have caused forces into the control column. Undue movements of the blades in the plane of rotation have proved similarly undesirable effects on the control column. Severe resonance in the blades of some machines has been noted. By placing the flapping hinges on the center of rotation, by placing the control column fulcrum on the same center, by setting the vertical hinge at an angle, all these defects have been removed. The new and improved hub has been designed as the result of intensive research. By means of a new transmission it has also been found possible to "jump" the machine considerably higher than before. Fuller particulars of these improvements will be awaited with great interest.

The new Pitcairn autogiro will have an all metal stressed skin fuselage and all the refinements of a modern transport. It will be a pusher of the "roadable" type, and with a 165 horse-power engine the maximum speed is expected to be 130 miles per hour.

When we consider what these remarkably capable men have done in the past we may be quite assured that Mr.

Pitcairn's anticipations will be completely realized in the very near future.

IV. FUNDAMENTAL PROBLEMS OF THE HELICOPTER.

Basic Requirements.

A mistaken conception of the helicopter problem is that it consists in the provision of an airscrew with sufficient thrust to get a machine off the ground and to maintain vertical climb thereafter. In reality the requirements of a practicable helicopter are complex and numerous, and have only been fully satisfied in one or two machines in spite of experiments extending over thirty years. These requirements may be stated as follows:

1. Ability to rise vertically with a substantial useful load in proportion to the power employed.
2. To descend vertically with power on, at a slow rate of speed.
3. To descend vertically at a reasonably slow rate of speed with the engine not functioning, particularly after sudden failure of the engine.
4. To climb on an inclined path, if desired.
5. To descend on an inclined path, with or without power.
6. To hover in space.
7. To maintain a reasonable rate of speed in horizontal flight.
8. Control and stability about all three axes of the craft in all the conditions of flight enumerated.
9. A moderate degree of maneuverability.
10. Freedom from torque or gyroscopic reactions.
11. No undue vibration or strains in normal operation.
12. Simplicity of construction and of control, mechanical reliability, particularly in the transmission of power, and structural strength combined with light weight.

It has been a long struggle to meet all these requirements, and it is not surprizing that Cierva and many other workers in rotary aircraft have been and are of the opinion that the windmill rotor offers a more practical objective; that the autogiro has progressed more rapidly than the helicopter; that even to-day, when the helicopter has achieved so much,

thanks partially to knowledge derived from autogiro development, it still has in the direct take-off giro a rival it is not likely to supplant.

While the full technical consideration of the problems involved would necessitate a large volume rather than a short paper, we shall nevertheless attempt to outline the general methods whereby these requirements can be met.

1, 2. Ability to Rise Vertically and to Descend Vertically with Power On.

If the first requirement is met, then the second requirement is satisfied. The ability to rise vertically is something which can be obtained with ease in the light of modern aeronautics. We have efficient blade elements and an excellent understanding of the correct setting of these elements. We also have both theoretical and experimental evidence to the effect that high vertical thrust in pounds per horse-power may be achieved by giving a large mass of air little downward velocity, so that the kinetic energy loss of the downwardly moving air is reduced to a minimum. In other words we need only provide an efficient airscrew with a large diameter and disk area in relation to the horse-power it is required to absorb; to avoid so large a diameter that high lift is achieved at the expense of efficiency in forward flight (a delicate problem for the aeronautical designer); and to maintain overall dimensions and weight of the lifting airscrews within reasonable limits.

3. Ability to Descend Vertically with Power Off.

Here we are faced with several problems: it is necessary that under engine failure the positive pitch setting of the lifting airscrew shall be rapidly changed to the smaller or even negative setting of the freely rotating windmill so that the airscrew may continue to rotate in the same direction and retain lift in vertical descent. At the same time it is essential that the motor shall be instantaneously declutched. Whether changing the pitch and declutching the motor should be manual or automatic (with an overrunning clutch in the transmission system) is a question yet to be answered. But the mechanical problems involved are not insuperable, and have been met in a number of reasonable ways. Finally there is the requirement that the disk area swept out by the blades

shall be large enough to make the descent slow, a requirement which is fortunately similar to that postulated in considering vertical ascent.

4. Ability to Climb on an Inclined Path. 5. Ability to Glide Down on an Inclined Path, Without Power.

These may, in the helicopter be considered subsidiary problems and if vertical ascent and descent are secured, these two requirements are certain to be satisfied, particularly because less power is required for a given lift when the airscrew is in a lateral airstream.

6. Ability to Hover.

It is clear that if vertical ascent is achieved, hovering will depend upon the stability and control obtainable when the aircraft is virtually at rest but at some altitude above the ground. With a hovering machine, it is clear that the ordinary stabilizing and control surfaces as employed in the airplane become ineffective, since the stabilizing and control action of such surfaces is predicated on the presence of a rapid airstream. If the usual stabilizing surfaces are ineffective, then the inherent stability must be sought in the characteristics of the rotor or rotors themselves and in their disposition with regard to the center of gravity of the aircraft. The question of inherent stability of a hovering machine has been insufficiently explored either in the wind tunnel or by theoretical investigation. Some workers have been pessimistic regarding the inherent stability of a single rotor and have advocated the use of two or even four rotors. Others have maintained that the coming of a flapped rotor would provide dihedral action so that a displacement in roll, let us say, accompanied by side slip would automatically produce a restoring moment. In the absence of thorough research or adequate practical experience, it seems proper to postulate that for the hovering condition there shall be full control to compensate for any lack of inherent stability. Since, in hovering, the ordinary surfaces of the airplane are as ineffective in control as they are in stabilizing, control must be sought within the rotor itself. Tilting the rotor axis is not a promising method, since tilting the rotor while hovering

introduces the translatory motion, which is the negative of hovering. A more promising method is to provide blade pitch variation at certain points of the rotational cycle, which is the method resorted to by most workers. Unfortunately even this is not entirely free from objection, since control in roll is then likely to be accompanied by a yawing moment, though a yawing moment should be sufficiently damped by vertical tail surfaces. Even when two rotors are disposed on either side of the fuselage, the same difficulties are inherent. Granted blade pitch variation however, and the development of technique by pilots, it will probably be found that sufficient control will be attainable for the short periods of time that hovering will be resorted to.

It has also been suggested that large surfaces might be disposed in the slip stream of the airscrew, rotatable in whole or in part about horizontal or vertical axes. Such surfaces possibly cambered could then be used in a variety of ways as

(*a*) To block off the slip stream on either side of the longitudinal axis; (*b*) block off the slip stream ahead or in rear of the vertical axis; (*c*) to provide drag elements on either side of the machine; (*d*) to provide lateral forces ahead or in rear of the vertical axis; (*e*) to provide drag elements acting down on one side or other of the machine.

It is clear that a large field of speculation is opened up by the use of auxiliary surfaces, and also evident that with the use of auxiliary surfaces the ideal of three independent controls about the three axes of an aircraft could be obtained. The objection is that with the low velocity of the slip stream, and the large disk areas of the airscrews, such surfaces would be apt to become large and unwieldy in actuation. Also they are apt to add undesirable parasite area. On the whole it would seem more logical to seek control of the hovering helicopter neither in tilting rotors nor in the use of auxiliary surfaces, but rather to seek variation of blade angles, following the direct control methods of Wilford, and Hafner.

7. Ability to Maintain a Reasonable Rate of Horizontal Speed.

The three elements to be considered here are of course the efficiency and drag of the rotor as a lifting element, the propulsive efficiency, and the parasite drag. Surprizingly

little information of an experimental character is available on the first two elements. Many memoirs or reports of a theoretical character have been written by well-equipped aerodynamicists, but the complexity of the subject is such, the assumptions which have to be made in order to get tractable mathematics are so numerous, that too great reliance should not as yet be placed on theoretical conclusions —particularly when they are ultra enthusiastic. There is also the fact that theoretical simplifications are always such as to increase estimates of efficiency, by neglecting radial components of flow, interferences between blades, and the losses due to the fact that fields of flow round blade elements have to undergo such rapid variations or alterations, introducing what might be termed aerodynamic hysteresis.

Since we have already compared fixed airfoil machine with the autogiro or gyroplane rotor, the logical step is to compare helicopter efficiency in forward speed with the efficiency of the autogiro under similar conditions. The comparison should first of all be between the autogiro and the helicogyro or the helicopter in which an independent propulsive airscrew is employed. If the helicopter airscrew is rigidly disposed, that is if it neither feathers nor flops, then its basic efficiency in forward flight may be expected to be quite low, even if the pitch of the blade as a whole is adjusted to suit ascent or forward flight conditions. If the rigid blade is correctly disposed in advancing motion, then it will meet the air in a disadvantageous manner in the subsequent retreating motion. The introduction of flapping motion about a horizontal pin, so that the blade is free to adjust itself and to equalize lift between the advancing and the retreating stage, is almost certain to give a somewhat higher efficiency. A feathering blade with some mechanical control opens up the possibility of setting the blade at the most advantageous position at every phase of the circular motion. In the gyroplane the mechanical control of the feathering is intended primarily to neutralize rolling and yawing moments and secure autorotation, whereas in the two rotor helicopter, the objective could be mainly an increase in efficiency. Hence the hypothesis appears justifiable that a mechanically controlled feathering machine might work out a trifle better than either the autogiro

or the gyroplane rotor in horizontal flight. But the helicopter would need extra weight in the mechanical transmission, and with its two rotors supported by lengthy bracing on either side of the machine (carrying the transmission also) the parasite drag would be much higher than in the case of the autogiro, where the mounting of the rotor is now a well streamlined affair of little drag. If two coaxial airscrews are used, parasite drag is eliminated, but there are prejudicial interferences. In all probability there would ultimately be little to choose regarding efficiency in forward flight between the helicogyro (as we have defined it) and the autogiro.

When the true helicopter is considered, in which the propulsive airscrew is eliminated, the situation appears very much better, though the claims frequently made that such an aircraft would soon attain speeds greater than those of the fastest airplanes are perhaps fantastic. A naive argument employed to substantiate these claims runs somewhat as follows: The resultant thrust lies substantially along the axis of the rotor. Let us incline this axis forward and we secure a horizontal component of the thrust which is equal to the resultant thrust multiplied by the sine of the angle of inclination. Therefore we can secure any desired horizontal thrust simply by inclining the axis of rotation more and more. And if the parasite drag of the rest of the machine is kept down to a minimum, immense forward speeds are within reach. It is probably true that for small inclinations the "sine" conception just stated is correct. But as soon as the axis of rotation is appreciably inclined, the disk swept out by the blades has an appreciable area perpendicular to the air stream, and the rotor as a whole works in a peculiar "yawed" position. As a result the effective component of horizontal thrust does not increase anything like as fast as the sine of the angle of inclination. Instead of relying on the sine law, exponents of the true helicopter would do far better to base their claims of high efficiency in forward flight on another argument. In the machine in which propulsion is achieved by inclination of the rotor axis, an intermediate conversion of energy is eliminated. In the airplane, in the autogiro, in the gyroplane, in the helicogyro, the power of the engine is converted into propeller thrust with a loss of some twenty

per cent.; and then the propeller thrust is used to overcome the parasite drag and the drag of the lifting element, whether fixed airfoil or rotor. In the true helicopter the power of the engine is transmitted directly to a rotor, which is at the same time both a lifting and a propulsive element. It is on this ground, all other things being equal, that the true helicopter appears to be more promising in forward flight than other rotary wing types of aircraft.

8. Control and Stability about All Three Axes under Varying Conditions of Flight. 9. A Moderate Degree of Maneuverability.

Except in hovering or vertical ascent and descent, the stability and control of a helicopter, and particularly the lateral stability of a twin rotor helicopter, should offer little difficulty. The disposition of the two rotors so that their planes of rotation form a transverse dihedral with one another should give a result similar to that obtained from the transverse dihedral of an airfoil. Longitudinal stability should be obtainable by the use of horizontal tail surfaces, and directional stability by provision of vertical tail surfaces. It should also be recalled that longitudinal and lateral stability have been achieved in the autogiro-rotor. The helicopter airscrew, even if power driven, may have flapping blades, and possess analogous characteristics of stability when incorporated in an aircraft. If rotor controls have been provided adequate for the hovering condition, then there should be no greater difficulty in providing control in forward flight than with the autogiro. Again if there is no difficulty in obtaining control, and if gyroscopic torques are eliminated, adequate maneuverability would follow as a matter of course.

10. Freedom from Torques or Gyroscopic Reactions.

The attainment of adequate lift for a given horse-power presupposes a large diameter rotor, and if the diameter is large, it also follows that slowly rotating lifting airscrews must be employed with the motor r.p.m. eight to ten times as high as the rotor r.p.m. Since horse-power is proportional to the product of torque and revolutions per minute, the torque developed must of necessity be large. In the windmill rotor of the autogiro or gyroplane, there is fortunately no torque

to worry the designer; in the helicopter the elimination of torque effects (without which elimination fuselage and pilot would spin round dizzily in space) has proved troublesome and has led to a variety of conceptions. These ideas will be illustrated presently in the discussion of various helicopters built, but the reasoned classification of the most important methods utilized in torque elimination hitherto should be useful:

a. Two airscrews mounted on a common vertical shaft and rotating in opposite directions. It is only necessary to have a hollow shaft driving the lower airscrew in one direction, and an interior shaft projecting beyond the outer hollow shaft and drawing the upper airscrew in the opposite direction. Such arrangements have been used in very highly powered single seater fighters of small dimensions where the high engine torque otherwise rendered lateral control very difficult, and also in the autogiro where lateral control would otherwise be insufficient at very low speeds. The mechanical principles involved are simple, though very careful design is required. The more cogent criticism of the coaxial screw arrangement is that when two airscrews are mounted one above the other interaction between the screws reduces the thrust in vertical ascent with power and also reduces the lifting capacity in vertical descent without power. Since this interference is really a question of halving the disk area of two airscrews working without superposition, no amount of skilful design can eliminate this effect entirely. Even though the interaction would be less in forward flight, the criticism is a serious one. Also with two superposed airscrews torque effects are not identical, and even if the two airscrews have been carefully designed with slightly different blade settings or diameters, the torque effects will not be entirely eliminated.

b. Another arrangement is to place one airscrew behind the other, or to have four airscrews arranged at the corners of a square. Here the criticism is that in forward flight, the rear airscrew is powerfully influenced by the wash of the forward propeller, with adverse effects on the stability and possibly the efficiency.

c. Another idea is to use a single large airscrew with its real advantage in providing a large disk area for given overall

dimensions with small propellers mounted on the blades driven by independent motors mounted behind them. While torque may be eliminated in this fashion, the complexity of whirling small engines round in space is appalling. It is only a trifle less complex to mount the small propellers at the tips and to drive them by mechanical transmission from the single main engine.

d. The idea of rotating a single main airscrew by hydraulic reaction jets at the tips of the lifting blades may be dismissed as in the realm of the fantastic.

e. Again it has been frequently suggested that a single main airscrew might be employed, with an auxiliary airscrew mounted on outriggers at the rear or at the end of the fuselage and providing a lateral thrust to counteract the reaction torque. A long transmission becomes necessary and power is wasted in the production of lateral thrust.

f. An alternative plan is to mount a large vane in the slip stream or downwash of the main airscrew, and so rotate a part of the vane that a lateral force is produced to counteract the torque. The vane unfortunately has to assume large proportions and constitutes a parasitic element of some importance.

g. Passing over some other arrangements, an interesting plan is to place two airscrews rotating in opposite directions on either side of the fuselage. The objections are that two transmission systems are necessary, and that when the disk area of a single screw is equally divided between two screws, the diameters of the two screws added together are greater than the diameter of the single screw in the ratio of 2 to 1 so that overall dimensions are increased. In spite of these objections, this last arrangement seems to be the one which has the most general approval at the moment.

Gyroscopic reaction is again eliminated by the use of two screws rotating in opposite direction, or else by the system of flapping blades as employed in the autogiro if a single screw is used. Some workers in the helicopter field have attached much value to the stabilizing effect of gyroscopic action and Florine in Belgium actually built a two rotor machine with the two airscrews rotating in the same direction, but with axes skilfully inclined so as to counteract torque reaction.

But while gyroscopic effects may be helpful to stability, they oppose controllability and maneuverability, and it would seem better to eliminate gyroscopic effects rather than to have them counteracted by the controls.

11. Vibration and Strain. 12. Simplicity of Construction and Control, etc.

It would take us too far afield in the realm of mechanical design to discuss the problem of vibration. Vibration is a difficult problem even with the fixed wing airplane. One will readily admit that to eliminate vibration in the helicopter with its long and light transmission, and peculiar and changing aerodynamic conditions, is an imposing task. Other difficult design problems present themselves in the long transmission which must be effective yet so light as to be suitable for aircraft work; in the various controls necessary to change blade settings either for all blades simultaneously, as when passing from power on to power off vertical descent, or in changing blade settings on one side of the rotor shaft only for control purposes; in the cooling of the engine by a blower or auxiliary propeller when the machine is deprived of the rapid airstream of forward flight; in the outrigger system to carry the airscrew, etc.

In general it may be said that while the requirements of a practicable helicopter are now well understood, and can now be met, the difficulty in designing and building a helicopter is far greater than in developing an autogiro—just as the autogiro is a greater challenge to the engineer than is the airplane itself.

V. VARIOUS CONCEPTIONS OF THE HELICOPTER.

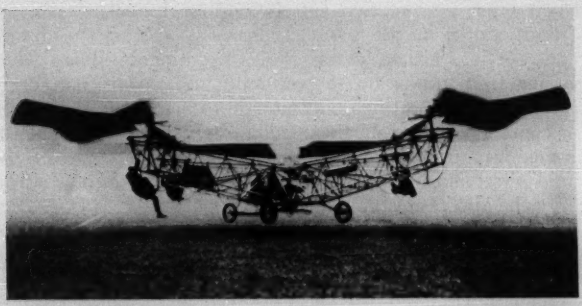
It is impossible in the compass of one paper to discuss the many conceptions of the helicopter which have engaged attention at various times. The following descriptions of the more notable developments may serve however to illustrate the present state of the art.

De Bothezat Helicopter.

While the De Bothezat Helicopter was built and flown some fifteen years ago (1922–1923) it is interesting to recall it because the designer, Dr. George De Bothezat, is now

constructing a machine of modern conception, and because the original De Bothezat helicopter illustrates many of the ideas previously discussed. It was provided with four lifting airscrews each of 26½ ft. diameter, four-bladed, with wide blades (5 ft. toward the tip) giving a total blade area of 900 sq. ft. A maximum thrust of 1500 lbs. was obtained from each airscrew. The central power plant from which transmissions were directed to the four corners of a square consisted of the B.R. 2 stationary air-cooled engine developing 200 hp. While repeated flights were made, no definite record of performance is available. Unofficial reports indicate that

FIG. V-1.



De Bothezat Helicopter lifting three men in addition to the pilot, April 17, 1923.

the De Bothezat helicopter was moderately satisfactory in control and stability and in the photograph of a flight (Fig. V-1) a man is seen hanging on at the extreme end of the rear arm, with his weight totally unbalanced. We have previously mentioned the utility of the dihedral principle in helicopter work. This principle was utilized in the De Bothezat machine, with the planes of rotation of the lateral and longitudinal airscrews, respectively, disposed at a dihedral angle to one another. Control was secured by making all the lifting propellers variable and reversible in pitch, and by placing two small variable-pitch directional control propellers, with axes horizontal, on either side of the fuselage. Forward

motion was secured by tipping the axis; in fact with complete control available and symmetrical disposition of the lifting elements motion in any direction whatsoever was possible and sometimes motions arose which were not desired.

According to the testimony of Captain Sergeiesky at the hearings of the Dorsey Bill before the House Military Affairs Committee, Dr. De Bothezat has now done much design and development work on a new machine which is termed the Heli-hop. Piecing together the testimony offered, these seem to be the main features of or claims for the new machine:

1. It is to be a very small helicopter, weighing, complete with engine, only about 300 pounds and able to carry a man with machine gun and ammunition. The statement reads: "This would give rise to an entirely new method of warfare, battalions of swift and silently-flying machine guns, able to land at night behind the enemy's lines, even in rough country."

2. A structural weight only 60 per cent. that of airplanes of the same power.

3. Greater performance than with an airplane of the same power.

4. A solution of the problem of inherent stability by making use of suspended blades. (Two conjectures can be made: That the blades are freely hinged, or else that the entire airscrew has some freedom in relation to the fuselage, so that a species of pendular stability is introduced.)

5. Two airscrews, mounted on the same shaft and rotating in opposite directions.

6. A motor of 2000 r.p.m. with 10 to 1 reduction to the airscrew.

Berliner Combination Airplane and Helicopter.

The Berliner combination helicopter and airplane is mainly of historical interest, as an example of one of the earlier machines having achieved control and horizontal flight, but in retrospect it is clear that the path of progress did not lie in this direction—in spite of the most ingenious and careful work by the inventor. The machine shown in the photograph of Fig. V-2 achieved horizontal flight in 1922. A later machine, a triplane, flew in 1924 one minute and 35 seconds and achieved an altitude of about fifteen feet. Two lifting

airscrews of 15 ft. diameter were driven from a Bentley rotary engine of 200 hp. and a control airscrew was placed at the rear. Propulsion was achieved by tilting the axis forward. The machine weighed about 1,930 lbs. The fundamental difficulties are clear: lifting screws had too small a disk area; airplane surfaces interfered with airscrew functioning and vice versa; control was uncertain.

Pescara Helicopter.

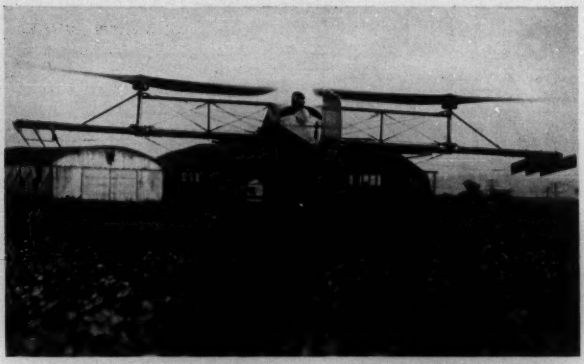
From the end of the Great War up to 1925, the Spaniard, Marquis Patéras Pescara, built a variety of machines all on similar lines to those shown in Fig. V-3 with very indifferent results. Pescara had biplane rotors mounted on the same shaft, with blade incidence variation for control. The failure of his persistent efforts is generally attributed to lack of stability. A non-flapping rotor system, with weights closely concentrated so that there is little moment of inertia, and with no dihedral between two rotors, appears to lack inherent stability and to be very sensitive to disturbances.

Baumhauer's Helicogyro.

The experimental machine of Von Baumhauer (Fig. V-4), a noted Dutch engineer, illustrates that type of direct lift machine in which the torque of the single lifting airscrew is neutralized by the thrust of an auxiliary airscrew disposed at the rear end of the fuselage. Baumhauer's machine was completed in 1930 and was in the air for about 5 minutes at a few yards above the ground when mechanical difficulties led to the breakage of one of the blades. Von Baumhauer found that his single airscrew of 15.2 meters in diameter, rotating at only 102 r.p.m. and driven by a rotary Bentley engine of 200 hp., gave him a lift of more than 1,300 kilograms. Propulsion was to be achieved either by inclination of the axis, or by the use of a conventional propeller. The rear propeller was operated by another rotary engine of 80 hp., which is an enormous expenditure of power for elimination of the torque. The pitch of the blades could be controlled either simultaneously or differentially at various points of the plane of rotation, but auxiliary control surfaces were also placed in the

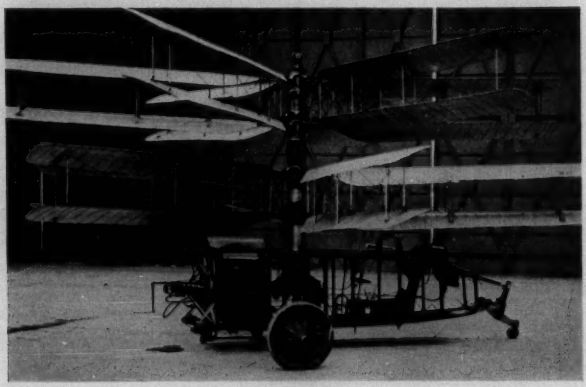
slip stream of the airscrew. It is a pity that the mechanical defect prevented Baumhauer from proving or disproving the validity of his conceptions.

FIG. V-2.



The Berliner combination helicopter airplane of 1922.

FIG. V-3.

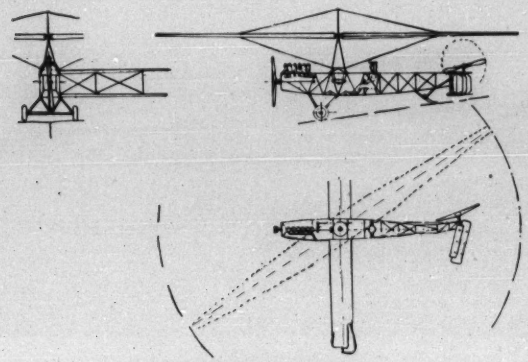


The Pescara with coaxial screws, which proved very sensitive to disturbances.

Hellesen-Kahn.

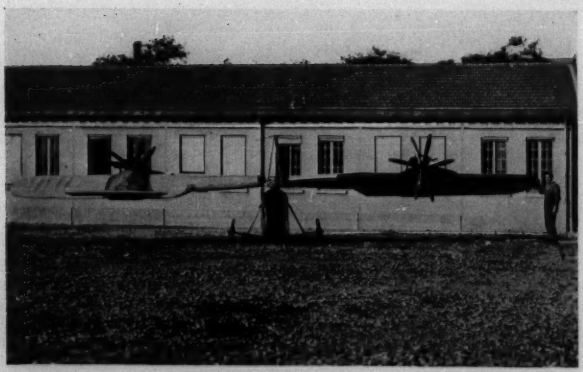
A photograph of the curious Hellesen-Kahn machine of 1930 is shown (Fig. V-5) merely to illustrate the type in which reaction torque is avoided by using rotating motors mounted

FIG. V-4.



The Baumhauer helicopter.

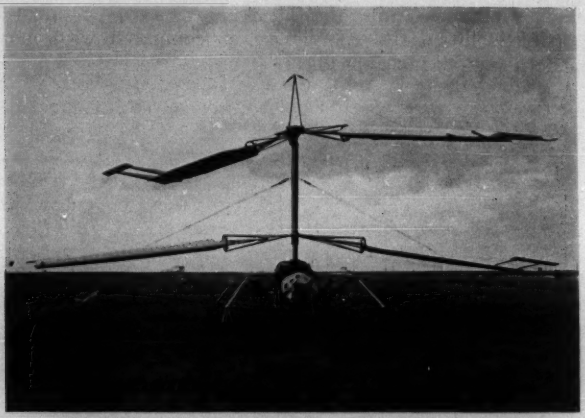
FIG. V-5.



The Hellesen-Kahn in which motors with auxiliary airscrew supplied the drawing force to a single-lifting element.

on the lifting wings, and applying driving effort to the blades by auxiliary airscrews. The Curtiss-Bleecker (U. S. A.) and the Issacco (France and England) belong to this classification. The mechanical complexities of whirling motors round in space, the additional conversion of energy involved and the inefficiency of the auxiliary airscrews make this type of aircraft very unpromising.

FIG. V-6.



The D'Asconio helicopter in which three auxiliary airscrews were used to secure control.

D'Ascanio Helicopter.

The D'Ascanio Helicopter is an interesting though somewhat complicated conception. On October 8, 1930, it broke three records of the period by a flight in Italy, in which it reached an altitude of 18 meters, a distance of 1,078 meters, and a duration of 8 minutes 45 seconds. Forward speed with a 95 hp. engine and a total weight of 800 Kgs. was slow, but films and reports of the Italian Air Ministry give an impression of remarkable stability and control. As shown in Fig. V-6, two coaxial rotors were used turning in opposite directions. Blades were articulated about axes parallel to the span and lying along the center of pressure, with small stabilizing

surfaces disposed in rear of each blade. Three small auxiliary airscrews were employed. One auxiliary horizontal airscrew was placed at the rear to give longitudinal control and inclination of the axis for forward flight; the other auxiliary horizontal airscrew provided stability in control and yaw. Still another auxiliary airscrew rotating in a vertical plane took up the residue of the reaction torque and gave directional control. Blade incidences could be varied simultaneously by the pilot, and pitch was changed automatically in case of engine failure. While the D'Ascanio helicopter offers a possible solution, its complexity as compared with more modern types is not appealing.

FIG. V-7.

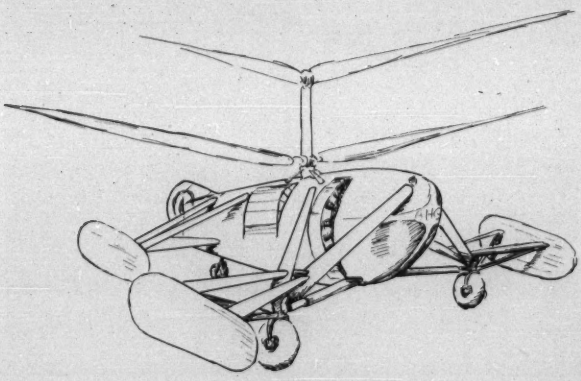


Diagram of the Asboth helicopter.

Asboth Helicogyro.

The Hungarian engineer Oscar von Asboth has built four or five types of helicogyro, the first having been flown in Budapest in 1928, and has made numerous flights in several countries, with satisfactory evidence of stability and control and forward speed, etc. It is understood that development work is being pushed energetically. The main interest of the very scanty published information lies in the following features (Fig. V-7):

1. Simplicity in the power plant and transmission.
2. Simplicity in the blade system which involves flexible blades with no flapping hinges.
3. Stability and control obtained by multiple hinged surfaces or vanes placed in the rotor slipstream.
4. Adequate vertical lift with airscrews rather small diameter.
5. One of the few direct lift machines.

The type is one which deserves study and on which further information is desirable.

Bréguet Helicopter.

That aircraft which ranks next to the Focke helicopter in achievement is probably the Bréguet (termed Gyroplane by its inventor) which Monsieur Bréguet flew in 1935 as the culmination of nearly twenty years work and the construction of a whole series of direct lift machines. The Bréguet gyroplane has met two of the conditions imposed by the French Air Ministry: it has flown at more than 500 meters in a closed circuit at an altitude of more than 10 meters and has exceeded a speed of 100 kilometers an hour. With a 350 hp. engine, the weight empty is 1,430 Kgs. and gross weight is 2,030 Kgs. with about 200 Kgs. of fuel and oil. The total upward thrust has been measured to be 3,200 Kgs., giving a large amount of thrust available for rapid vertical flight.

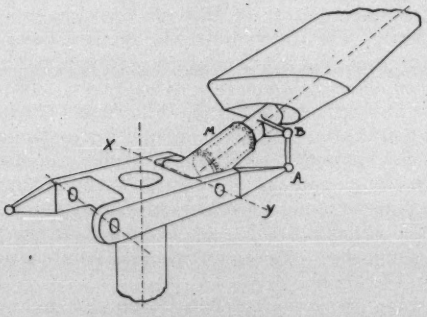
The Bréguet is a pure helicopter (Fig. V-8) with two four-bladed airscrews rotating in opposite directions on a single vertical shaft. The rotors have the de la Cierva flapping hinge at the root, and also some articulation about a vertical hinge placed about half way out on the blade. The Bréguet rotors bear analogy however to the Wilford and Hafner rotors. As Fig. V-9 indicates, the blades, in addition to flapping, have provision for automatic feathering. When an articulated blade rises swinging about the axis X Y, the linkage is such that if the point A remains fixed in space, the root of the blade turns in the bearing M in such fashion that the angle of incidence diminishes. Hence the rotor is a combination of the flapping and feathering types.

The raising and lowering of the point A found on all the blades is effected by a rotating circular drum which can be

FIG. V-8.

The Breguet gyroplane: one of the most successful helicopters in flight.

FIG. V-9.



Combined flapping and feathering system of the Breguet.

given any desired inclination in space by appropriate controls from the cockpit. The flexibility of this control is such that by appropriate changes in blade incidence simultaneously or differentially there could be secured (*a*) lateral control, (*b*) directional control, (*c*) inclination of the plane of rotation so that propulsive thrust was available *without* inclination of the axis, and (*d*) longitudinal control. There is evident similarity to Wilford's and Hafner's work, and it is noteworthy that propulsive effort can be obtained without inclination of the aircraft as a whole. An adjustable horizontal stabilizer helps in securing trim, and a vertical rudder is no doubt utilized in forward flight.

The Bréguet gyroplane has shown a performance inferior to that of the Focke, with a more powerful motor and is a very much heavier machine. Also difficulties have been reported in that flapping of the blades caused blade tips to come too closely together. From this the inference has been drawn that the Focke formula of two lifting airscrews on either side of the fuselage is a far superior one. It is rash to draw such a conclusion. There are many obvious improvements to be effected in Bréguet's design, such as decrease in solidity ratio, use of three blades instead of four, and a radical change in the landing design. M. Bréguet had evidently not enough confidence in his control or he would not have designed so clumsy an undercarriage, perfectly "safe," no doubt, but with an enormous amount of parasite drag. Also it is clear that the fuselage might very well be streamlined.

It is highly significant that a man of vast aircraft experience and technical ability such as Bréguet has implicit experience in further developments of his principle, and in a memoir before the French Academy of Sciences, he has presented studies of a huge helicopter flying boat capable of transatlantic flight at a very high rate of speed. Schematic diagrams are shown in Fig. V-10.

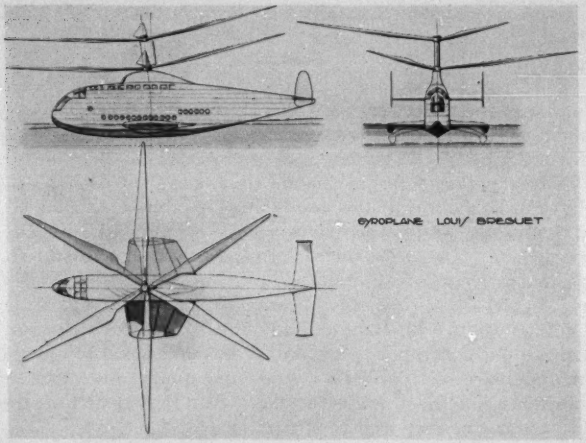
Focke Helicopter.

After immense research, both theoretical and in wind tunnel, Professor Heinrich Focke has developed a machine which has recently attracted great attention and has surpassed all previous helicopter records.

Fig. V-11 shows a general view of the machine. Fig. V-12, an outline of the dihedral arrangement of the wings, and Fig. V-13 displays an experimental flight with the fuselage still uncovered.

It will be noted that after full consideration of the problem of torque elimination Focke decided on the arrangement of two airscrews disposed on either side of the fuselage. Even though

FIG. V-10.



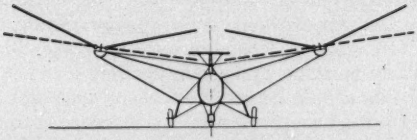
Breguet's conception of a giant helicopter for transatlantic service.

we may agree with the general view that such an arrangement is preferable, we also see that there is quite a problem in bracing two airscrews mounted in this fashion. The wings are pronouncedly tapered in their form with the widest chord at the root. It is not certain that a similar form of taper could be employed in an autogiro rotor, where the necessity of autorotation must be kept more strongly in view. But in the lifting power driven airscrew, it is logical to provide a wider chord for the inner, more slowly rotating portion of the blade so as to give a better distribution of the lift, following airplane practice in which tapered wings are so frequently employed.

FIG. V-11.

General arrangement of the Focke helicopter.

FIG. V-12.



Dihedral setting of the two Focke airscrews.

FIG. V-13.

An experimental flight in the Focke helicopter.

Whatever may be Professor Focke's views on the inherent stability of a single rotor, he has embodied a lateral dihedral in the arrangement of the airscrews, and has also retained a horizontal stabilizer. Elevator and ailerons have disappeared, but the rudder remains (probably a wise measure, since it is the rudder alone which can give a control in yaw uncomplicated by a subsidiary moment in roll). Following La Cierva, Focke has used flapping blades hinged freely about a substantially horizontal pin, and in all probability this has been done for three reasons: A flapping blade gives a higher efficiency than a rigid blade in forward flight; the elimination of bending moments makes for a considerably lighter blade, and a flapping blade has inherent stability in itself. In the control of the blades, the latest device of Cierva, the tilting or direct control rotor, has not been followed. The control derives rather from Wilford or Hafner practice, with blade pitch variation ahead or behind the axis of rotation, or on either side of the axis of rotation. Since the Focke helicopter in vertical descent without power passes rapidly from the power driven stage to the autorotative stage, blade pitch decrease there must be, hence it is entirely logical that blade pitch variation should be used for control purposes also.

Three blades on each screw of moderate diameter were developed by intensive wind-tunnel research. The diameter is rather smaller than one expects in a helicopter. No doubt some degree of climb has been sacrificed so as to secure greater forward speed.

The mechanical difficulties in the bevel-gear drive from the engine mounted at the forward end of the fuselage were surmounted by careful design and test. A friction coupling was included in the transmission system. A small airscrew mounted at the nose of the fuselage serves to cool the motor when vertical ascent, descent, or hovering fails to give sufficient cooling airstream. In all other respects Focke followed conventional airplane practice.

The actual figures of performance have been checked by representatives of the International Federation of Aeronautics. With a machine carrying a single occupant, and a small amount of fuel (this is perfectly legitimate, particularly as in a small helicopter the weight of the transmission is much

more of a handicap than it would be in a much larger machine), with a gross weight of 950 kilograms or about 2,190 pounds, the figures are: vertical climb at the rate of about 12 feet a second; altitude obtained 7,500 feet; endurance 1 hour 20 minutes; range 67 miles; speed 74 miles an hour.

Some uncertainty exists as to the horse-power of the engine, but it is rumored to have about 200 horse-power. If that is indeed the case, the high speed is well below that of an autogiro of approximately the same gross weight and horse-power. But against this inferiority must be placed the fact that the Focke is the first example of its type, and that many aerodynamic refinements are evidently possible. A cantilever supporting structure, for example, would certainly give an appreciable improvement in high speed.

There is not the slightest doubt that all previous helicopter records have been surpassed, but what is still more remarkable is the perfect control achieved in all regimes of flight. The German aviatrix Fräulein Reitsch has actually flown the helicopter straight out of the hangar and has performed all manner of remarkable evolutions.

The Platt Cyclogiro.

The Cyclogiro, while discarded at least for the time being and never flown, deserves mention because it is based on a highly ingenious principle, and because its failure to show adequate aerodynamic efficiency in wind tunnel test contradicted promising theoretical computations, and demonstrated the danger of relying solely on theoretical computations in the highly complex field of rotary aircraft.

The Cyclogiro was invented simultaneously in the United States by H. H. Platt, a mechanical engineer of great ability, in Germany by Dr. Adolph Rohrbach, a well known airplane designer, and again by Laskowitz in America. It is shown in the diagrammatic sketch of Fig. V-14 in both the Platt and the Rohrbach conception the Cyclogiro consisted of a fuselage of conventional form, supported by two power-driven paddle-wheel rotors, one on each side rotating about the lateral axis. The cyclogiro rotor comprised three or more blades oscillated by cams during rotation in such a manner as to produce a resultant force. By adjusting the cams so as to alter the

amplitude and the phase angle of the oscillation with respect to the direction of flight, the direction and magnitude of the resultant force could be varied, and in particular both lift and propulsive effort could be obtained as in an inclined helicopter airscrew or simply lift, or lift and a backwardly directed propulsive force. With independent controls of the rotors on either side yawing and rolling moments could be obtained, simultaneous control of the rotors on either side provided longitudinal control. With power off, a practicable form of autorotation was obtainable. The position of the center of

FIG. V-14.

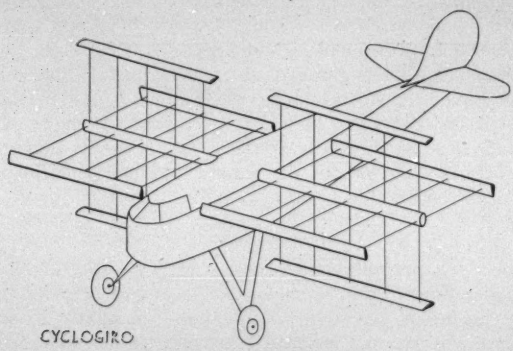


Diagram of the Platt Cyclogiro.

gravity in relation to the horizontal axis of the rotor could be adjusted so as to counteract the motor torque. The most careful theoretical considerations (with some allowance for interference) indicated high efficiency of the system, and had the wind tunnel tests substantiated the calculations of high efficiency, the rotor would have met all the basic requirements of the helicopter. But in the theoretical calculations there was integration of the forces developed by blade airfoil elements, substantially as if they were isolated in space. But in actual test, interferences, the production of a highly complex flow pattern, and the "aerodynamic hysteresis" involved in the changing flow round the blades, resulted in very disappointing values of the equivalent lift/drag ratio.

The Platt Vertigiro.

Mr. Platt has also given much thought to another type of direct lift machine in which the advantages of a single airscrew have been retained by providing vanes placed in the slip stream of the airscrew to take up the reaction torque. Gyroscopic moments are avoided by blades hinged in the autogiro. The Platt Vertigiro is a true helicopter because propulsion is secured by tilting the rotor axis. The inventor states: "The

Fig. V-15.

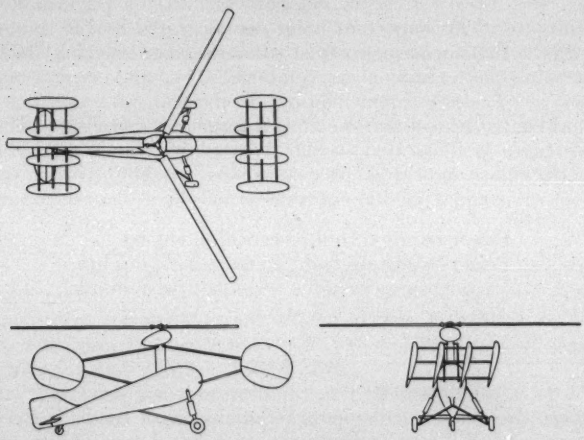


Diagram of the Platt Vertigiro.

machine may be moved forward, backward or to either side by the appropriate inclinations of the rotor axis as produced by displacement of the control stick." The three blades are hinged in autogiro fashion, so that stability is inherent within the rotor itself.

The anti-torque vanes have their lower surfaces hinged and may be used for lateral and directional control, while tilting of the rotor axis provides the longitudinal control. An interesting novelty is the provision of an automatic pitch

control, similar in principle to the governor control of the constant speed controllable pitch propeller. Change from the blade setting necessary in powered flight to the blade setting necessary for vertical descent is entirely automatic. By putting standard reduction gearing near the rotor, by putting the blower-cooled engine low in the fuselage with the shaft vertically disposed and in line with the rotor axis, a practicable and light power plant has been provided.

A great deal of ingenious mechanical design, arduous theoretical work, coupled with wind tunnel experimentation at New York University, support Mr. Platt's performance estimates. An important point demonstrated by the tunnel tests is that an autogiro type rotor may be designed which acts in efficient fashion as a combined lifting and efficient airscrew. The large areas required for the multiple anti-torque and control vanes are of course a target for criticism. The Vertigiro is illustrated in the diagram of Fig. V-15. The performance indicated for a 3,000 lbs. machine, with a 44 foot rotor and a 300 hp. engine is as follows:

Power required to lift vertically, 185 hp.
Power to sustain flight at 60 m.p.h., 110 hp.
Vertical rate of climb, 1,800 feet per minute.
Top level speed, 126 m.p.h.

Further Research.

As a conclusion to this rapid survey, we can say that every one of the fundamental requirements of the helicopter have now been met, including an adequate degree of general performance. It cannot yet be said, however, that a definite type of solution has emerged, and a great deal of aerodynamic, dynamic and mechanical research remains to be done, with some typical problems as follows:

1. The efficiency of the airscrew in combined lift and propulsion. Should the airscrew be of the flapping or feathering type, or a combination of the two? Should mechanical controls be introduced into the rotational cycle to secure maximum propulsive efficiency? What plan, form, and thickness ratios should be employed?

2. The efficiency of the power-driven airscrew used for lift only. What should be the characteristics of such an airscrew? Definite information must also be obtained on efficiency of the true helicopter rotor as compared with the power-driven lifting airscrew in combination with a conventional propeller.

3. In what directions should inherent stability of the helicopter be sought? Is it sufficient to rely on the inherent stability of the flapping autogiro rotor, or should stability be sought in appropriate dihedral disposition of the two or more rotors relative to one another?

4. Is it really necessary to abandon the simplicity and aerodynamic cleanness of the two screws on a single vertical shaft, and resort to the Focke formula of airscrews mounted on either side of the fuselage? Or is it possible to use two coaxial, flapping screws without sacrificing too much lift capacity in vertical ascent or descent?

5. Can the conversion from powered rotation to the autorotative condition be made entirely automatic?

6. What is the best possible mechanism for incidence changing and control?

7. Should not a motor be specially designed for helicopter use, perhaps a rotary engine, or one in which both crankshaft and crankcase would rotate at unequal speeds, so as to simplify transmission? Should not the motor be specially designed for hovering and slow speed conditions?

We have listed merely a few typical problems. Such listing would be indefinitely extended by engineers working on the helicopter problem in earnest.

It is this large number of parameters and problems which make the helicopter so fascinating a study quite apart from its utility.

VI. CONCLUSIONS

A Future for All Types. The Dorsey Bill.

The writer is thoroughly convinced that there is a splendid future for rotary wing aircraft with no one type emerging supreme, and this conviction is based on the theoretical considerations briefly outlined, actual achievements recorded and on the multiplicity of sound and novel ideas which are in the

minds of exponents of rotary aircraft. It must be remembered that only a fraction of the time, energy and money which have been expended on the airplane have been given to the development of the autogiro. The airplane at its birth had no competing craft to fear, and all the energy of original and adventurous minds, all the far-sightedness of commercial interests were directed into the one channel. Rotary wing aircraft appearing in practicable form at a considerably later date had to meet the fact that the ablest engineering minds were already deeply engaged in airplane research, and that a certain vested interest in the commercial side of aircraft already existed.

As a result of this situation, to every inventor, scientist or engineer ever engaged in rotary aircraft work there have been and now are at least a hundred well qualified men concerned with the progress of the airplane. Again instead of receiving the vast flow of public capital which has been the not unmixed blessing of the airplane, the autogiro has had to rely almost wholly for its costly experimentation on the generosity of such altruistic men as Lord Weir in England and Harold Pitcairn in the United States, who since purchasing the La Cierva American rights in 1929 has been generous and determined beyond measure. Apart from the many striking and recent achievements of rotary aircraft, there are two reasons why we may soon see a remedy to the situation. First, the passage of the Dorsey Bill, which permits the Secretary of War to expend the sum of $2,000,000 in furtherance of rotary aircraft with the probably wise provision that no purchases shall be made of any type which has not already flown. This bill should shortly remedy the financial situation and encourage all workers in the field, executives and engineers alike to greater efforts. Second, the growing pressure which is being brought to bear on University Schools of Aeronautics to provide increased facilities for graduate study and research in the field of rotary aircraft. Speaking solely for the institution with which the writer has the honor of being connected, it may be said that every effort will be made to measure up to the legitimate desires of the rotary aircraft enthusiasts, and to select and train the very ablest young minds to serve in this great field

of research [The De La Cierva Memorial Committee, a most distinguished and representative body of men is also working to a similar end].

Autogiro or Gyroplane versus the Helicopter.

There are very definite reasons why we may conclude that, as previously said, no one type will emerge and displace all others. Something has already been said regarding the respective merits of the autogiro and the gyroplane. The specific question remains as to whether the autorotative blades will be displaced by power driven blades. In favor of the helicopter there exist two powerful arguments: One is the possibility of greater efficiency by virtue of the fact that the conversion of engine power into propeller thrust, and the subsequent action of the propeller thrust in overcoming the drag of the lifting system, is shortcircuited when the airscrew serves as both the lifting and the propulsive element. Mathematical calculations and wind tunnel experiments apart, the avoidance of an intermediate conversion of energy, leads to the instinctive belief in greater efficiency. Second is the fact that the helicopter is apparently the very final step in man's conquest of the air as far as flexibility and ability to achieve anything and more than nature has achieved with bird or insect. It is a most fascinating prospect to be able to rise, descend, hover, move back or forward and to convert man completely to a three-dimensional being, and our instinctive urge is not to stop short of this goal which is inherent in the helicopter. But there are many advantages which the autogiro or gyroplane has as compared with the helicopter. It has greater simplicity since no considerable transmission of power is involved; greater safety since in the case of engine failure there is no need for immediate transformation from one rotor regime to another; greater simplicity again because there is no reaction torque to overcome by the use of airscrews rotating in opposite directions, etc. . . .; and lesser difficulties in keeping down weight; and smaller overall dimensions because the autogiro needs but a single rotary element. Vibration in the helicopter will be an even more intricate problem than in the autogiro. Again looking at the question from a different point of view, it is clear that with the addition of the "jump-

off" feature the autogiro already comes very near to all that we really need to achieve in the helicopter. The helicopter is a most promising and fascinating type of aircraft whose development should be pushed with all possible energy, but it has not displaced the autogiro, and those engaged in autogiro work should not be discouraged for an instant by the recent helicopter advances.

IX. AIRPLANES VERSUS ROTARY WING AIRCRAFT.

It may also be definitely concluded that there is not the slightest chance that the airplane will be in any way outmoded by rotary wing aircraft. No matter what claims may be made for a greater speed with rotary wing, or for the attainment of very much greater speeds in the future with retention of the low speed qualities, there is no doubt that the airplane wing greatly surpasses any rotor in aerodynamic efficiency. Nor have the possibilities of improving the slow speed characteristics by the utilization of slots, flaps, and extensible portions of the wing surface been fully exhausted. There is one argument in the flapped airplane versus giro controversy which has been ably set forth by Elliott Daland at a recent meeting of the National Air Board. Very low speeds, say 20 to 25 miles per hour, may well be achieved by the flapped and slotted airplane. But an airplane designed to this end would have an immense wing area, and would have high structural weight, very little useful load and would in general be a clumsy and impractical vehicle. The giro with a minimum speed of 20 m.p.h. is on the other hand an entirely practicable vehicle. As a method of high speed transportation, particularly with large machines, there is not the slightest doubt that the airplane will remain supreme for a great many years to come. On the other hand, airplane people are entirely in the wrong when they speak disparagingly of the rotor airfoil or fail to take due note of its advances. Certainly the rotor will not displace the airplane, but it is just as certain that the rotor will have its specific field of action. Aviation people would do far better to recognize frankly that in rotary aircraft there lies the possibility of greater popularization of flying, the possibility of roof top landings for postal service, the possibility of ferry service between airports, of effective

use in crop dusting, in fire prevention, in forest patrol and in many other ways. The far-sighted airplane man would do far better to welcome the rotor as an available auxiliary in the final conquest of the air, and to extend to the rotor every possible aid.

There is one more reason why airplane people in general should welcome every advance made by rotors, namely that each branch of heavier-than-air craft influences and advances the other. Thus autogiros and helicopters have been greatly assisted by the structural technique and airfoil development of the airplane. On the other hand, the safety ideas of the giro have had a decided influence on aircraft practice. The helicopter has borrowed methods of control from the gyroplane, flapping blades from the autogiro. There are many other instances of such interplay.

Future Possibilities and Research.

It is the writer's deepest conviction, based not only on some knowledge of the art but on a deep-seated "hunch," that rotary aircraft are only in the initial stages of development, and that a brilliant future lies just ahead, with perfect mastery of the air as the goal. Of course much difficult work lies ahead, but there is also a fascinating field of research ahead for the aerodynamicist, the structural man, the mechanical engineer. The problems for research and experimentation are numerous and enticing for all these workers: the stability of the lifting airscrew; the greater efficiency of the rotor in forward flight; the achievement of complete control under all conditions of flight; the mechanical design of transmissions and controls; the combination of all this with appreciable useful loads and adequate horizontal speed. No more interesting work in applied science is available to-day to the inventor, the engineer, the theoretician.

Electron Microscope.—(*Engineering*, Vol. CXLVI, No. 3797.) An instrument in which the "lenses are of the electromagnetic type is that designed and patented by Dr.-Ing. Bodo von Borries and Dr.-Ing. Ernst Buska, now made by Messrs. Siemens and Halske, Berlin-Siemenstadt. The chamber forming the body of the instrument is continuously evacuated and the electron stream is produced by a hot cathode at the top to which a potential of 100,000 volts is applied. There are two electro-magnetic "lenses," one above the other, the upper lens near which the object is placed acting like the objective of an optical microscope and the lower lens magnifying the virtual electron image formed by the upper lens similarly to the eyepiece of an optical microscope. For inserting a photographic plate of fluorescent screen a form of vacuum lock is provided at the bottom of the instrument. With this instrument it is possible to obtain useful magnifications of the order of 30,000 diameters, as compared with about 2000 diameters, which is the limit for the optical microscope, the resolving power of the latter being limited by the wavelength of the light used. According to de Broglie's wave-particle theory the wavelength of the wave system accompanying an electron is very much shorter than that of visible or ultra-violet light, and the resolving power of the electron microscope is correspondingly greater. As a result of this resolving power it is possible to detect organic or inorganic particles with dimensions of the order of 100 Angstrom or even of 10 Angstrom units. The instrument lends itself well to the examination of viruses and bacteria, but to protect such organic bodies from the heating effect of the electron stream they are coated with an extremely thin film of collodion. In addition, the electron microscope has numerous technical applications such as obtaining information on the properties of clays, cements, etc., and on the preparation of ores.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

RELATION OF CAMERA ERROR TO PHOTOGRAMMETRIC MAPPING.

In connection with the work of the different agencies of the Department of Agriculture, large areas of the United States are being photographed from the air. The primary purpose of this photographic work is the checking of crop control and of projects for the prevention of soil erosion. In view of the lack of precise maps for much of this country, it is considered desirable to have these photographs so made that they will also serve for the construction of topographic maps. Unfortunately the requirements for the two purposes are not parallel. The Department of Agriculture is interested in securing photographs from which areas can be scaled with the least difficulty. This implies photographs made from great altitudes with lenses of long focal length and relatively small angular field of view in order that displacements arising from relief in the terrain may not introduce large errors in areas read from the photographs by planimetric devices. On the other hand, for making topographic maps, photographs covering a wide angular field of view, made with a lens of medium or short focal length, are desirable in order that displacements arising from the presence of relief may be pronounced; such displacements being necessary for the drawing of contours.

Before the possibility of using photographs for these dual purposes can be adequately considered it is necessary to have a knowledge of the manner in which errors of the airplane camera are propagated and finally appear as errors in the map. Furthermore, a photograph to serve the two purposes will probably involve compromises from both standpoints and cameras of high precision must be used in order to obtain the best results from the photographs. In RP1177 in the *Journal of Research* for February, Irvine C. Gardner, chief of the

* Communicated by the Director.

Bureau's Optical Instruments Section, derives the formulas covering camera performance and presents the information necessary for the preparation of specifications for precision cameras, and for the preparation of specifications for photographic projects. This report has been prepared as a part of committee work for the American Society of Photogrammetry.

ELASTIC PROPERTIES OF CAST IRON.

An optical method for measuring the deflection of cast iron transverse test bars up to the breaking strength has been developed by A. I. Krynitsky and C. M. Saeger, Jr., of the Bureau's Metallurgy Division. Deflection is determined by measuring the distance between a reference point and a rubber band mounted on the test bar. The deflection readings are independent of any movement of parts of the testing machine.

As reported in RP1176 in the February *Journal of Research*, irons were heated to maximum temperatures of 1400°, 1500°, 1600°, and 1700° C. Test bars 1.2 inch diameter were cast vertically, bottom poured in green sand molds at 100°, 150°, 200°, and 250° C. above the liquidus temperature. Transverse properties of the test bars were determined by interrupted loading and by direct loading up to breaking load. From the data obtained the total, plastic, and elastic deflections, modulus of rupture, relative modulus of elasticity, total, plastic, and elastic resilience were determined for all test bars investigated. The load-elastic deflection curves are not straight lines. The relative modulus of elasticity was determined on the straight-line portion of the elastic deflection curve and also at the breaking load. In general, the lowest and highest elastic properties were observed for the maximum heating temperatures of 1400° and 1700° C. respectively. These properties showed a tendency to decrease with an increase of pouring temperature.

The microstructure of the test bars was examined. The finer graphite particles are associated with higher transverse properties. A laminated, pearlite-like structure observed on some unetched specimens, and the presence of large graphite particles subdivided into hexagonal-like grains, are of particular interest.

STRUCTURAL PROPERTIES OF MASONRY WALLS.

Tests on six different types of masonry walls (part of the Bureau's investigation of the structural properties of low-cost house constructions) are described in Building Materials and Structures Report BMS5, which has just been released. The compressive and transverse strengths of some of these wall constructions had been determined in previous investigations, but information on their other structural properties was lacking.

The following constructions were represented: High-strength brick, cement mortar, excellent workmanship; medium-strength brick, cement-lime mortar, commercial workmanship; medium-strength brick, cement-lime mortar, excellent workmanship; structural clay tile on end, cement-lime mortar, excellent workmanship; structural clay tile on side, cement-lime mortar, excellent workmanship; and stone-concrete block, cement-lime mortar, excellent workmanship.

The specimens were subjected to compressive, transverse, concentrated, impact, and racking loads to simulate loads actually applied to the wall of a house. Usually three duplicate specimens were tested.

The deformation under load and the set after the load was removed were measured for uniform increments of load up to the maximum, except for concentrated loads, for which the set, only, was determined. The results not only give information about these particular types of masonry walls, but should prove valuable as a criterion for judging new or unusual types of construction.

Copies of this report are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 15 cents each.

STANDARD TESTS ON BUILDING BRICK.

Most organizations and individuals must depend upon the written word for directions in carrying out laboratory test methods. Obviously, where accuracy and reproducibility of results depend upon rigid adherence to a particular testing technique, standard methods should be very explicit. The

test of a standard method is the agreement in the results of independent laboratories working on the same or comparable samples.

The results of such a test are reported in the January number of the *Bulletin of the American Society for Testing Materials* in a paper by W. J. Krefeld of the Civil Engineering Research Laboratories of Columbia University and J. W. McBurney of the Bureau entitled "Comparison of Standard Tests on Building Brick by Two Laboratories."

The program involved the selection of 30 whole bricks as nearly alike as could be judged by visual inspection. These 30 bricks were numbered from 1 to 30, wrapped separately and divided at random into two samples of 15 bricks each. Each of the two coöperating laboratories received one of these samples and the following tests were made:

(1) Water absorption was determined by 24-hour cold immersion and by 5-hour boiling on the whole bricks after they had been dried.

(2) The transverse Strength was measured after redrying.

(3) Water absorption by 24-hour cold immersion and by 5-hour boiling was redetermined on both sets of half bricks resulting from the transverse test.

(4) Compressive strength, flatwise, was determined on the dried half bricks constituting the first set and the second set of halves was exchanged with the coöperating laboratory.

(5) Both laboratories determined water absorption by 24-hour cold immersion and by 5-hour boiling on these exchanged halves, and then measured compressive strength on the same specimens after drying.

The only instructions were that both laboratories should use the methods bearing the ASTM designation "C 67–37." No consultation or correspondence took place between the laboratories on the subject of methods until after completion of all tests. Both laboratories completed their tests and submitted their reports to a third party without knowledge of the results obtained by the other coöperator.

A statistical study of the data resulting from these tests appears to justify the following conclusions:

(1) The agreement between the two laboratories testing identical specimens was better than that obtained by either

laboratory testing the two halves of the same brick. In other words, the accuracy of the absorption tests exceeded the reproducibility of the samples, unless the samples were identical.

(2) The saturation coefficients (ratios of absorption by 24-hour cold absorption to absorption by 5-hour boiling) differed by 0.002 for Sample 1 and by 0.000 for Sample 2 when identical specimens were tested by both laboratories.

(3) Standard Methods of Test C 67–37 provides a water absorption test of satisfactory accuracy and reproducibility and that two laboratories, working independently and without previous comparison of methods, should check each other so closely on identical samples, indicates that C 67–37 provides sufficiently exact directions for procedure.

(4) The accuracy and reproducibility of the compressive strength test are poor in comparison with the absorption test. Random errors of considerable magnitude are apparent and a systematic error caused by difference in strength of capping materials is possible.

DIFFERENCES IN THE POROSITIES OF DIFFERENT SECTIONS OF A BRICK.

In a study of pore structure and its relation to the resistance of brick to disintegration by freezing and thawing, under investigation by R. T. Stull and P. V. Johnson, it became evident that the porosity varied within different parts of a brick, due to the manner in which the brick was formed or to uneven pressure in forming.

As a means of determining the extent of the variation in porosity within certain bricks, four specimens were selected to include a salmon stiff-mud, a hard-burned stiff-mud, a salmon dry-press and a hard-burned dry-press brick.

Each brick was sawn across the flat side into nine equal sections, thus giving sections representing one center, four corners and four middle sections between two corner sections and adjacent to the center section.

The porosity of each section was determined by the air expansion method. The maximum porosities were obtained with the center and the minimum with a corner section, and

the porosities of the middle sections a little higher than the mean of the two. In the hard-burned, stiff-mud brick of 20.7 per cent. porosity, as determined on the whole brick, the sections varied in porosities from a minimum of 17.2 per cent. at a corner to 22.7 per cent. as the maximum at the center, while the salmon stiff-mud brick with 29.5 per cent. porosity, determined on the whole brick, varied in sectional porosities from 27.0 per cent. as the minimum at a corner to 31.6 per cent. as the maximum at the center.

In the salmon and hard-burned dry-press bricks there was no definite trend in direction of change in porosities such as was observed in the stiff-mud bricks. Although the variations in porosities of the sections were, in general, as great as those of the stiff-mud bricks, the variation did not occur in a systematic manner. The hard-burned, dry-press brick varied in sectional porosity from 23.1 to 26.0 per cent., with an original porosity for the whole brick of 24.6 per cent., while the salmon dry-press brick, whose original porosity for the whole brick was 29.9 per cent., varied in porosity from 27.6 to 33.7 per cent. for the sections.

PLASTIC CALKING MATERIALS.

During the past ten years the Bureau has been called upon to test thousands of samples of plastic calking materials intended for use in Federal Government buildings. The purpose of testing cannot be well explained without a consideration of the purpose of the materials. Essentially, they are intended to seal narrow openings or joints between parts of the structure which cannot be successfully sealed with relatively inelastic materials, such as cement mortar. Structural movements caused by temperature changes, settlement, and volume changes resulting from wetting and drying of the structure, cause these joints to vary in width. The plastic calking compounds are intended to fill narrow openings and to remain sufficiently pliable to adjust themselves to such structural movements. The compositions are, in general, a mixture of treated oils with fillers to form a mastic of suitable consistency. Particularly in masonry buildings, this type of joint filler is subjected to severe conditions. Masonry, as

well as many other building materials, is porous and hence capillary effects come into consideration. The removal of some of the oil from the mastic by the pores of the adjoining material causes considerable shrinkage. The mastics usually contain volatile matter, varying from 1 to 25 per cent., which evaporates, causing further shrinkage. When shrinkage occurs, the mastic may separate from the materials which it is supposed to seal, and lose a sufficient amount of plasticity to render the performance under service conditions unsatisfactory.

The tests designed to determine the quality of the mastic joint fillers may be described as performance tests, which place the samples under conditions as nearly as possible like those in service. They also simulate the most difficult condition, namely, that of joint extension, which shows whether the bonding properties are sufficient and whether the plastic properties are such as to enable the mastic filler to maintain a seal. Other properties which are determined are the ability of the material to remain in joints in warm weather when the plastic condition is another important property when the mastic is in contact with porous materials of high capillary properties.

In these tests an exceedingly large number of failures have occurred, which indicate that fabrication methods have not been sufficiently standardized, and possibly also that the producers have not given adequate consideration to all of the conditions which the materials are called upon to withstand. An investigation is in progress which involves a study of the composition, fabrication, and properties of these products. An analysis of failures has led to the conclusion that one of their most common causes is excessive shrinkage. Another is the lack of proper adhesive qualities, permitting an easy separation of the mastic from the structural materials to be sealed together. A third cause is too rapid drying out and embrittlement of the mastic, which may be defined as a loss of plasticity. Still another occasional cause of failure as shown in certain samples is stratification and breakage in the middle of the joint, as if the cohesive properties were at fault.

The concern of the builder in the failure of such a minor part of the structure is not merely that of replacement, but rather the injury that may be caused to other parts through the

use of a poor joint filler. If the mastic fails to seal the joint, water will find entrance to the interior and cause considerable damage, and in many cases necessitate expensive repairs. If the consistency is at fault, the mastic may flow from the joint and over the face of exterior building materials. Then there will be great difficulty in cleaning because the oil may penetrate into masonry materials, and hence cleaning is not merely a matter of removing the mastic from the surface. Furthermore, if the oil-retaining properties are insufficient, the oil will spread from the joints into adjoining masonry units, producing an unsightly condition which is practically impossible to eradicate.

In the course of study on these materials an article has been prepared by D. W. Kessler for publication in the *Review of the Society of Residential Appraisers*, which discusses in some detail the purpose, uses, composition, and properties of the plastic joint fillers. The article also outlines a few field tests which are suitable for use at the site of construction projects, where laboratory facilities are not available. It is believed that the use of such tests by building superintendents or calking contractors might prevent some of the undesirable results experienced through the use of improperly fabricated plastic joint fillers.

SURVEY OF ROOFING MATERIALS IN THE SOUTHEASTERN STATES.

As part of the Bureau's research program on building materials and structures, a survey has been made of the weathering qualities and extent of use of various roofing materials in the Southeastern States.

This survey, which was made with the coöperation of the representatives of the Reconditioning Section, Home Owners' Loan Corporation, both in Washington and in the field, involved approximately 3500 miles of travel. Detailed studies of the weathering characteristics of the different roofing materials were carried out in Greensboro, N. C., Columbia, S. C., Savannah and Atlanta, Ga., Jacksonville and Orlando, Fla., Birmingham, Ala., Knoxville, Tenn., and Charleston, W. Va.

Observations were made on the extent of use of the various

roofing materials on new and old construction in the cities included in the survey; also a tabulation was made, by States, of the kinds of roofing materials on more than 10,000 rural and small town dwellings, along approximately 2500 miles of highway.

Approximately 400 photographs, showing types of weathering of roofing materials and features of design and construction of roofs, were taken. From these, 48 were selected for publication in the report of this survey. This report, the sixth to be issued in the series entitled "Building Materials and Structures," BMS6, is obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 15 cents a copy.

STRUCTURAL PROPERTIES OF "FABRIHOME" CONSTRUCTIONS FOR WALLS AND PARTITIONS.

Report BMS11 of the series on building materials and structures, which was released a short time ago, describes tests on 18 specimens of walls and partitions submitted by the Curren Fabrihome Corporation. The specimens were manufactured by the Johnson Metal Products Company and represented constructions marketed under the trade name "Fabrihome." These constructions consist of non-load-bearing panels having welded sheet-steel frames with plywood outside faces and gypsum-board inside faces for walls, and gypsum-board faces for partitions. The panels were designed to be fitted into a concrete frame and fastened by springs.

The specimens were subjected to transverse, concentrated, and impact loads, simulating those in an actual house. The loads were applied to both faces of wall specimens. For each of these loads, three like specimens were tested.

The deformation under load and the resulting set were measured for uniform increments of load up to the maximum, except for concentrated loads, for which the set only was determined. The results are presented graphically and in tables.

Copies of BMS11 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents.

Lamps and Lumens—Their Consumption and Cost.—S. G. HIBBEN. (*The Electric Journal*, Vol. 35, No. 10.) The use of artificial light, with corresponding although not parallel rate of growth in kilowatt-hour consumption, has increased enormously in the United States. Multiplying the total number of lamps by the average watts per lamp shows an increase in kilowatt consumption of about 50 per cent. during the period 1933–7. Correspondingly, the average lumens or quantities of generated light per unit have increased as represented by a growth of 11 per cent. If the average annual increase for the past 15 years should be approximately the same during the next five years, there would be an expectancy in the United States of a growth in incandescent lamp consumption of between 15 million and 20 million lamps (bulbs) annually. Contrary to some popular fallacies, there is no deadlock between reduced prices for lighting and increased consumption of power. Neither one awaits the overtures of the other, but both go hand in hand under the incentive of increased volume of production and consumption. In the decade between 1927 and 1937 the American consumer of domestic electric power for household use found his payments for kw.-hr. reduced on the average from 6.9 cents to 4.5 cents. Part of the explanation for increased lighting usage is traceable to lessened cost of electric lamp bulbs, which, since 1908, experienced an almost unbelievable reduction. Neither has the lumen output per lamp been neglected for a 60 watt lamp that produced less than 500 lumens in 1908 had grown to 550 lumens in 1915, 620 lumens in 1922, 700 lumens in 1930, and about 835 lumens today. Indeed, it is not unexpected that lighting has increased, for the customer may now obtain five times the light of three decades ago for the same cost.

R. H. O.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, FEBRUARY 17, 1939.

The regular monthly meeting of The Franklin Institute was called to order by Dr. Henry Butler Allen at 8:30 o'clock, p.m.

The minutes of the previous meeting were approved as published in the Journal.

The additions to membership since the last report were as follows:

Active	13
Associate	11
Student	31
Total	55

The Chairman then announced that this was a joint meeting with The American Philosophical Society and was the conclusion of the Symposium on the Progress in Astrophysics which began in the Hall of The American Philosophical Society this morning. He then introduced Dr. Henry Norris Russell, of Princeton University who spoke on "Stellar Energy and the Evolution of Atoms."

The speaker pointed out that the only known source of energy which could keep the sun shining as long as it has is the transformation of hydrogen into helium or other heavier atoms. Processes recently discovered in the laboratory could accomplish this, and would occur at about the right rate at the temperature of the sun's interior. The probable history of a star was also discussed. The subject was illustrated by lantern slides.

After a brief discussion the thanks of the meeting were extended to the speaker.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, February 8, 1939*).

HALL OF THE COMMITTEE,
PHILADELPHIA, FEBRUARY 8, 1939.

MR. WILLIAM G. ELLIS *in the Chair.*

The following reports have been presented:

No. 3063, No. 3064. The Standing Committee on the Franklin Medal recommended that Franklin Medals be awarded to Edwin Powell Hubble of Pasadena, California, "In recognition of his extensive study of the nebulæ, particularly those outside our galaxy, as a result of which the dimensions of observed space have been greatly increased," and Albert Sauveur (posthumously), of Cambridge, Massachusetts, "In recognition of his outstanding work in the

science of metallography, and of his many contributions to this branch of metallurgy which have been in a large measure responsible for changing the heat treatment of steel from an art to a science."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 830 readers made use of the facilities during the twenty-five days of January.

RECENT ADDITIONS.

Agriculture and Forestry.

NICOL, HUGH. Plant Growth Substances. 1938.

SIGMOND, ALEXIUS A. J. DE. The Principles of Soil Science. Translated from the Hungarian by Arthur B. Yolland. 1938.

Astronomy.

SMART, W. M. Stellar Dynamics. 1938.

Automotive Engineering.

TAYLOR, C. FAYETTE, AND EDWARD S. TAYLOR. The Internal Combustion Engine. First Edition. 1938.

Aviation.

DUNCAN, RICHARD. The Aircraft Flight Instructor. 1938.

JORDANOFF, ASSEN. Your Wings. 1936.

SIMMONS, VIRGIL. Air Piloting. 1938.

Biography.

FRANKLIN, BENJAMIN. The Autobiography of Benjamin Franklin, Poor Richard's Almanac and Other Papers. 1936.

JEHL, FRANCIS. Menlo Park Reminiscences. Vols. 1–2. 1936–1938.

SIKORSKY, IGOR I. The Story of the Winged-S: an Autobiography. 1938.

SMEATON, JOHN. John Smeaton's Diary of his Journey to the Low Countries 1775. 1938.

Biology and Biochemistry.

FURNAS, C. C., AND S. M. FURNAS. Man, Bread and Destiny. 1937.

JENSEN, HANS F. Insulin: its Chemistry and Physiology. 1938.

WELLS, A. LAURENCE. The Microscope Made Easy. 1938.

Chemistry and Chemical Technology.

Beilsteins Handbuch der Organischen Chemie. Bd. 28, erster Teil: General sachregister A-G.; Bd. 30–31: Naturstoffe. Three volumes. 1938.

BÖMER, A., A. JUCKENACK AND J. TILLMANS. Handbuch der Lebensmittelchemie. Fünfter Band. 1938.

BOWDEN, SYDNEY T. The Phase Rule and Phase Reactions. 1938.

Deutsche Chemische Gesellschaft. Berichte. Autoren-general-register. Jahrgang 61–70. 1938.

HADERT, HANS. Casein and its Uses. Translation of Second German Edition with Additions by Dr. Henry Goldsmith. 1938.

HÄGGLUND, ERIC. Holzchemie. Zweite, gänzlich neubearbeitete Auflage. 1939.

HEMPEL, EDWARD H. The Economics of Chemical Industries. 1939.

HOUGEN, O. A., AND K. W. WATSON. Industrial Calculations. Second Edition. 1936.

International Committee on New Analytical Reactions and Reagents. Tables of Reagents for Inorganic Analysis. 1938.

JELLINEK, KARL. Kurzes Lehrbuch der physikalischen Chemie. Heft 1, 1938.

KARRER, PAUL. Organic Chemistry. Translated from the latest German Edition by A. J. Mee. 1938.

LATIMER, WENDELL M. The Oxidation States of the Elements and their Potentials in Aqueous Solutions. 1938.

LEWIS, WARREN K., AND ARTHUR H. RADASCH. Industrial Stoichiometry. First Edition. 1926.

MARSH, J. T., AND F. C. WOOD. An Introduction to the Chemistry of Cellulose. 1938.

MELLOR, J. W., AND H. V. THOMPSON. A Treatise on Quantitative Inorganic Analysis with Special Reference to the Analysis of Clays, Silicates and Related Minerals. Second Edition, Completely Revised and Reset. 1938.

Nederlandsche Chemische Vereeniging. Colloidchemistry Section. Hydrophobic Colloids. 1938.

SCHUMACHER, H. J. Chemische Gasreaktionen. 1938.

Dictionaries, Directories and Guide Books.

Bulletin Almanac and Yearbook. 1939.

DOUGLAS, GEORGE WILLIAM. The American Book of Days. 1937.

Minerva Jahrbuch der gelehrten Welt. 33 Jahrgang, 2 Bd. 1938.

Thomas' Register of American Manufacturers. 29th Annual Edition for 1939. 1938.

U. S. Works Progress Administration for the Commonwealth of Pennsylvania. Federal Writers' Project. Philadelphia: a Guide to the Nation's Birthplace. 1937.

World Almanac and Book of Facts for 1939.

Electricity and Electrical Engineering.

ALBERT, ARTHUR LEMUEL. Fundamental Electronics and Vacuum Tubes. 1938.

BERLINER, J. J., AND STAFF. Latest Developments in Storage Batteries. n.d.

GLOCKLER, G., AND S. C. LIND. The Electrochemistry of Gases and other Dielectrics. 1939.

MASSEY, H. S. W. Negative Ions. 1938. Cambridge Physical Tracts no. 1.

REICH, HERBERT J. Theory and Applications of Electron Tubes. First Edition. 1939.

Engineering.

Contributions to the Mechanics of Solids. Dedicated to Stephen Timoshenko by his Friends on the Occasion of his Sixtieth Birthday Anniversary. 1938.

Geology.

CLOOS, HANS. Einführung in die Geologie. 1936.
DAVISON, CHARLES. Studies on the Periodicity of Earthquakes. 1938.

Manufactures.

American Foundrymen's Association. Transactions. Vol. 46. 1938.
CRANE, E. V. Plastic Working of Metals and Power Press Operations. Second Edition. 1939.
HOFF, HUBERT. Die Hüttenwerksanlagen. Erster Band. 1938.

Mathematics

DEMING, W. EDWARDS. Some Notes on Least Squares. 1938.

Mechanical Engineering.

GIESECKE, FREDERICK E., ALVA MITCHELL, AND HENRY CECIL SPENCER. Technical Drawing Problems. 1938.
KEOWN, ROBERT MCARDLE. Mechanism. Revised and rewritten by Virgil Moring Faires. Fouth Edition. 1939.

Metallurgy.

BULLENS, DENISON K. Steel and its Heat Treatment. Volume 1: Principles, Processes, Control. Fourth Edition, Rewritten. 1938.
JENNY, A. Elektrolytische Oxydation des Aluminiums und seiner Legierungen. 1938.
LAMIRAND, J., AND H. PARISELLE. Métaux. Deuxième Édition. 1939. Cours de Chimie. Deuxième Partie.
NEWTON, JOSEPH. An Introduction to Metallurgy. 1938.

Mining and Mineralogy.

American Institute of Mining and Metallurgical Engineers. Transactions: Iron and Steel Division. 1938.
BAYLEY, W. S. Guide to the Study of Non-Metallic Mineral Products (Except Building Stone). 1930.
DAVISON, E. H. Field Tests for Minerals. 1937.
FRIEDENSBURG, FERDINAND. Bergwirtschaft der Erde. 1938.

Naval Architecture and Navigation.

MEADE, HILARY P. Sea Flags their General Use. 1938.
North East Coast Institution of Engineers and Shipbuilders. Symposium on Propellers. 1938.
WROTH, LAWRENCE C. Way of a Ship. 1937.

Photography and Graphic Arts.

KEPPLER, VICTOR. The Eighth Art. 1938.
Klimschs Jahrbuch des graphischen Gewerbes. Band 32. 1939.

NEBLETTE, C. B. Photography. Third Edition. 1938.
Penrose Annual. Volume 41. 1939.
SIMON, RICHARD L. Miniature Photography. 1937.
TAFT, ROBERT. Photography and the American Scene. 1938.

Physics.

BERGMANN, LUDWIG. Ultrasonics Translated by Dr. H. Stafford Hatfield. 1938.
COE, CARL JENNESS. Theoretical Mechanics. 1938.
FREI, HANS. Elektroakustische Untersuchungen in Hallräumen. 1936.
GOLDSTEIN, S., ed. Modern Developments in Fluid Dynamics. 1938.
MILLIKAN, ROBERT ANDREWS, Henry Gordon Gale, and Charles William Edwards. Manual of Experiments to Accompany A First Course in Physics. 1938.
WRIGHT, W. D. The Perception of Light. 1938.

Scientific Essays.

British Association for the Advancement of Science. Report of the Annual Meeting. 1938.
KORZYBSKI, ALFRED. Science and Sanity. 1933.

Sugar.

DAVIES, J. G. The Principles of Cane Sugar Manufacture. 1938.
PRINSEN GEERLIGS, H. C., AND R. J. PRINSEN GEERLIGS. Cane Sugar Production 1912–1937. 1938.
West Indies. Department of Agriculture. Reports on Agricultural Work in Barbadoes. Two Volumes. 1888–1922.

History of Shipbuilding.

Among the important additions to the library should be named Souvenirs de Marine, by Vice-Admiral Francois Edmond Pâris, in six volumes, published in Paris, between the years 1886-1910.

This is the most important survey ever published of the marine craft of all nations and all ages from the earliest Egyptian to the steamships of 1887. It consists of six large volumes containing 360 engraved plates. Each plate contains hull and sail plans and explanatory text sufficient to build an accurate reproduction of the craft either in full size or as a model. The contents include the important merchant and naval ships of the great periods of sail and steam together with local fishing and coasting craft, sailing yachts and marine engines. All the continents of the world are represented and the work of the Egyptian, Greek, Roman, Mediaeval, and Renaissance periods and the 17th, 18th and 19th centuries is exemplified.

The plans of existing vessels were obtained from actual measurements made by Admiral Pâris or by his correspondents in various parts of the world. The engravings of defunct ships are based upon the authority of contemporary models, sculptures, drawings and other documents.

Admiral Pâris was director of the marine museum in the Louvre for many years. These volumes reflect the depth of his knowledge, the extreme accuracy of his investigations and the sincerity of his devotion to marine lore.

C. M. G.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

NEUTRONS AND OTHER HEAVY PARTICLES IN COSMIC RADIATION OF THE STRATOSPHERE.*

BY

L. H. RUMBAUGH and G. L. LOCHER.

The apparatus, which was also carried on the second National Geographic U. S. Army Air Corps Stratosphere flight, was designed to test for the presence of radiations of various kinds—in particular, alpha particles, protons, and neutrons—in the incoming radiation.

Specially prepared photographic plates shielded, of course, from light, were exposed to the cosmic radiation. A portion of the area was left free for the purpose of recording any heavy ionizing cosmic-ray particles that might occur in the upper atmosphere, without regard to their origin. Portions of the plates were covered with paraffin to record possible cosmic-ray neutrons which would manifest themselves by the ejection of recoil protons. Other portions of the plates were covered with elements of various types in which cosmic-rays might produce nuclear disintegrations with the accompaniment of heavy particles, such as alpha particles and protons. In all cases, the intent was to seek for the final heavy particle radiations in the emulsion of the photographic film by microscopic examination.

The results are shown in detail in the original publication (National Geographic Society Contributed Technical Papers, Stratosphere Series, No. 2), and it will suffice to say that the only entities of the kind stated which revealed themselves were neutrons, and an upper limit to the neutron flux was fixed at 0.2 neutrons per square centimeter per second. The further conclusion reached is to the effect that at the altitude reached by the balloon, neutrons constitute a considerable

* Condensed from a paper published in full in the *National Geographic Society Contributed Technical Papers*, Stratosphere Series No. 2, pp. 32–36 (1936).

fraction of the cosmic radiation in number, though not in energy.

THE SOLUTION OF $\nabla^2\varphi - (1/c^2)\partial^2\varphi/\partial t^2 = -\alpha$.*

BY

W. F. G. SWANN.

Perhaps some apology seems necessary for giving a new method of arriving at the solution of the above equation whose solution is so well known. However, it is the experience of the writer that the usual forms of solution have in them certain elements which appear somewhat artificial to many physicists; and, for this reason a solution which proceeds in a straightforward manner may be of service.[1]

Starting then with the equation

$$\partial^2\varphi/\partial x^2 + \partial^2\varphi/\partial y^2 + \partial^2\varphi/\partial z^2 - (1/c^2)\partial^2\varphi/\partial t^2 = -\alpha, \quad (1)$$

we make the transformation

$$\xi = x, \quad \eta = y, \quad \zeta = z, \quad \rho = r, \quad \tau = t \mp r/c, \quad (2)$$

where $r^2 \equiv x^2 + y^2 + z^2$. We then find, immediately,

$$\frac{\partial}{\partial x} = \frac{\partial}{\partial \xi} \mp \frac{1}{c}\left(\frac{\partial r}{\partial x}\right)\frac{\partial}{\partial \tau} = \frac{\partial}{\partial \xi} \mp \frac{x}{rc}\frac{\partial}{\partial \tau} = \frac{\partial}{\partial \xi} \mp \frac{\xi}{\rho c}\frac{\partial}{\partial \tau}.$$

Analogous results hold for $\partial/\partial y$ and $\partial/\partial z$, so that

$$\begin{aligned} \frac{\partial}{\partial x} &= \frac{\partial}{\partial \xi} \mp \frac{\xi}{\rho c}\frac{\partial}{\partial \tau}; \qquad \frac{\partial}{\partial y} = \frac{\partial}{\partial \eta} \mp \frac{\eta}{\rho c}\frac{\partial}{\partial \tau}; \\ \frac{\partial}{\partial z} &= \frac{\partial}{\partial \zeta} \mp \frac{\zeta}{\rho c}\frac{\partial}{\partial \tau}; \qquad \text{also } \partial/\partial t = \partial/\partial \tau. \end{aligned} \quad (3)$$

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* Reprinted from the *American Physics Teacher*, **5**, 27 (1937).

[1] The solution usually given is that of G. Kirchhoff, Berl. Sitz., 641 (1882). Another proof has been given by Max Mason, *Phys. Rev.*, **15**, 312 (1920). The proof now given was developed by the writer for use in his classes on electrodynamics. As it is on the point of being submitted for publication, another proof following different lines has made its appearance; see S. Ballantine, J. Frank. Inst. **221**, 469 (1936).

Thus

$$\frac{\partial^2\varphi}{\partial x^2} = \frac{\partial^2\varphi}{\partial\xi^2} + \left(\frac{\xi}{\rho c}\right)^2\frac{\partial^2\varphi}{\partial\tau^2} \mp \frac{1}{c}\left(\frac{\partial}{\partial\xi}\left\{\frac{\xi}{\rho}\frac{\partial\varphi}{\partial\tau}\right\} + \frac{\xi}{\rho}\frac{\partial^2\varphi}{\partial\tau\partial\xi}\right). \quad (4)$$

Denoting the last expression in parenthesis by $(\ )_\xi$, and the corresponding parentheses in the expressions for $\partial^2/\partial y^2$ and $\partial^2/\partial z^2$ by $(\ )_\eta$ and $(\ )_\zeta$, respectively; and, observing further that $\partial/\partial\tau = \partial/\partial t$, and that $\xi^2 + \eta^2 + \zeta^2 = \rho^2$, we have, from Eq. (4) and its companions in y and z,

$$\{\nabla^2\varphi\}_{xyzt} = \{\nabla^2\varphi\}_{\xi\eta\zeta\tau} + \frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2} \mp \frac{1}{c}\{(\ )_\xi + (\ )_\eta + (\ )_\zeta\}, \quad (5)$$

where the subscripts to $\nabla^2\varphi$ denote the variables in terms of which ∇^2 is expressed. Thus, from Eqs. (1) and (5),

$$-\alpha = \{\nabla^2\varphi\}_{xyzt} - \frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2}$$

$$= \{\nabla^2\varphi\}_{\xi\eta\zeta\tau} \mp \frac{1}{c}\{(\ )_\xi + (\ )_\eta + (\ )_\zeta\}. \quad (6)$$

Let us seek the value of φ at the origin in the ξ, η, ζ, τ system, and let us surround the origin with a small sphere, which shall form part of the boundary, the main boundary being elsewhere.

Now Green's theorem, in three dimensions, is applicable as well in the ξ, η, ζ, dimensions of the group ξ, η, ζ, τ, as it is applicable in the x, y, z, dimensions of the group x, y, z, t. In one of its well-known forms,

$$\iiint\left[\varphi\nabla^2\left\{\frac{1}{\rho}\right\}_{\xi\eta\zeta\tau} - \frac{1}{\rho}\{\nabla^2\varphi\}_{\xi\eta\zeta\tau}\right]d\xi d\eta d\zeta$$

$$+ \iint\left\{\frac{1}{\rho}\frac{\partial\varphi}{\partial N} - \varphi\frac{\partial}{\partial N}\left(\frac{1}{\rho}\right)\right\}d\sigma = 0.$$

Since $\nabla^2(1/\rho) = 0$, we have, using Eq. (6),

$$\iiint\frac{\alpha}{\rho}d\xi d\eta d\zeta \mp \frac{1}{c}\iiint\frac{\{(\ )_\xi + (\ )_\eta + (\ )_\zeta\}}{\rho}d\xi d\eta d\zeta$$

$$+ \iint\left\{\frac{1}{\rho}\frac{\partial\varphi}{\partial N} - \varphi\frac{\partial}{\partial N}\left(\frac{1}{\rho}\right)\right\}d\sigma = 0. \quad (7)$$

Now

$$\frac{(\ )_\xi}{\rho} = \frac{1}{\rho}\left[\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho}\frac{\partial\varphi}{\partial\tau}\right) + \frac{\xi}{\rho}\frac{\partial}{\partial\tau}\left(\frac{\partial\varphi}{\partial\xi}\right)\right]$$
$$= \frac{1}{\rho}\left[\frac{\partial\varphi}{\partial\tau}\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho}\right) + \frac{2\xi}{\rho}\frac{\partial}{\partial\tau}\left(\frac{\partial\varphi}{\partial\xi}\right)\right].$$

Noting that $\partial\rho/\partial\xi = \xi/\rho$, we find immediately

$$\frac{(\ )_\xi}{\rho} = \frac{\partial\varphi}{\partial\tau}\left(\frac{3\xi^2}{\rho^4} - \frac{1}{\rho^2}\right) + 2\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right).$$

Analogous expressions hold for $(\ )_\eta/\rho$ and $(\ )_\zeta/\rho$, so that, since $\xi^2 + \eta^2 + \zeta^2 = \rho^2$, the integrand in the second integral of Eq. (7) becomes

$$\frac{\partial\varphi}{\partial\tau}\left(\frac{3\rho^2}{\rho^4} - \frac{3}{\rho^2}\right) + 2\left\{\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right) + \frac{\partial}{\partial\eta}\left(\frac{\eta}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)\right.$$
$$\left. + \frac{\partial}{\partial\zeta}\left(\frac{\zeta}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)\right\} = 2\left\{\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)\right.$$
$$\left. + \frac{\partial}{\partial\eta}\left(\frac{\eta}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right) + \frac{\partial}{\partial\zeta}\left(\frac{\zeta}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)\right\}. \quad (8)$$

On substituting this in Eq. (7), and converting the corresponding volume integral to a surface integral, we have

$$\iiint\frac{\alpha}{\rho}d\xi d\eta d\zeta + \iint\left\{\frac{1}{\rho}\frac{\partial\varphi}{\partial N} - \varphi\frac{\partial}{\partial N}\left(\frac{1}{\rho}\right)\right.$$
$$\left. \mp\frac{2\cos\theta}{c\rho}\frac{\partial\varphi}{\partial\tau}\right\}d\sigma = 0, \quad (9)$$

when θ is the angle between the outwardly drawn normal to the surface and the radius vector drawn from the origin at which φ is sought.

Now, in the contribution to the surface integral by the little sphere we have, in the limit, zero from $(1/\rho)\partial\varphi/\partial N$ and from $\mp(2\cos\theta/c\rho)\partial\varphi/\partial\tau$. The term $-\varphi(\partial/\partial N)(1/\rho)$ contributes $-4\pi\varphi$. Thus, with the surface integral now applying

to the main boundary, Eq. (9) yields

$$4\pi\varphi = \iiint \frac{\alpha}{\rho} d\xi d\eta d\zeta + \iint \left\{ \frac{1}{\rho} \frac{\partial \varphi}{\partial N} - \varphi \frac{\partial}{\partial N}\left(\frac{1}{\rho}\right) \mp \frac{2\cos\theta}{c\rho} \frac{\partial \varphi}{\partial \tau} \right\} d\sigma.$$

Here the integrals are taken at constant τ and $\partial/\partial N$ refers to differentiation along the normal in the coordinate system ξ, η, ζ, τ. Let us change to the variables x, y, z, t. Then $\partial/\partial\tau = \partial/\partial t$; and, if λ, μ, ν, are the directional cosines of the outwardly drawn normal to the surface,

$$\partial\varphi/\partial N = \lambda\partial\varphi/\partial\xi + \mu\partial\varphi/\partial\eta + \nu\partial\varphi/\partial\zeta,$$

so that from Eq. (3),

$$\frac{\partial \varphi}{\partial N} = \lambda \frac{\partial \varphi}{\partial x} + \mu \frac{\partial \varphi}{\partial y} + \nu \frac{\partial \varphi}{\partial z} \pm \frac{1}{c}\left\{ \frac{\lambda\xi}{\rho} + \frac{\mu\eta}{\rho} + \frac{\nu\zeta}{\rho} \right\} \frac{\partial \varphi}{\partial \tau}$$

$$= \frac{\partial \varphi}{\partial n} \pm \frac{\cos\theta}{cr} \frac{\partial \varphi}{\partial t},$$

where $\partial/\partial n$ refers to differentiation along the normal in the coordinate system x, y, z, t. Thus

$$4\pi\varphi = \iiint \frac{[\alpha]}{r} dx dy dz + \iint \left\{ \frac{1}{r}\left[\frac{\partial \varphi}{\partial n}\right] - [\varphi] \frac{\partial}{\partial n}\left(\frac{1}{r}\right) \mp \frac{\cos\theta}{r}\left[\frac{\partial \varphi}{\partial t}\right] \right\} dS, \quad (10)$$

which is the solution sought, and where if t is the time at which φ is sought at the origin, the understanding is that the quantities in square brackets are to be evaluated at $t = r/c$ if the minus sign is used in the last term of Eq. (10), or at $t = -r/c$ if the plus sign is used.

THE NATURE OF THE SOFT COMPONENT OF THE COSMIC RADIATION.*

BY

C. G. MONTGOMERY and D. D. MONTGOMERY.

W. F. G. Swann has shown that the experimental data are well satisfied if it be assumed that the soft component of the cosmic radiation is corpuscular in nature and charged, and loses energy according to the relation $-dE/dx = \lambda E + \alpha$, where α represents the energy lost in the excitation and ionization of the atoms per unit of path, and λE is the energy which is lost by the production of secondaries. One of the numerical values of λ which results from these considerations is 0.3 per meter of water. It is our purpose to discover what the nature of the primary corpuscles must be in order that they should lose their energy according to this law with this value of λ. The only candidates which we need consider are protons and electrons, since particles of greater mass or larger charge will not be able to penetrate to any great depths into the earth's atmosphere. The energy loss α is practically the same for both electrons and protons of high energy, and we cannot utilize its numerical value as a clue to the identity of the primary rays. Besides this constant energy loss, charged particles may lose energy by three processes: (*a*) by radiation, (*b*) by the production of pairs of electrons, and (*c*) by the production of showers. The cross sections for energy loss by processes (*a*) and (*b*) have been calculated by Bethe and Heitler,[3] and Nordheim.[4] The cross section for process (*b*) is only about 1/137 that for process (a). Although a theoretical mechanism for the production of showers has recently been given by Heisenberg,[5] and Oppenheimer,[6] the calculations are not as yet sufficiently detailed to give a value for the energy lost in this way. However, we may utilize the observations on the frequency of occurrence of showers to derive a value for this cross section in the following manner.

Let $F(E)dE$ be the number of primary rays of energy E crossing a unit area at sea level per second. The total

* Condensed from a paper which was published in the *Physical Review*, 51, 217 (1937).

amount of energy going into secondaries of these rays per unit path length is then $\int \lambda EF(E)dE$, where the integral is taken over all values of the energy. Let e be the average energy of a shower ray, and $R(N)$ be the frequency distribution of showers of N rays. For $R(N)$ we may take the experimentally determined form $R(N) = \gamma Z^2/N^3$,[7] and hence

$$\int \lambda EF(E)dE = \int_2^\infty eNR(N)dN = e\gamma Z^2/2.$$

Now the total flux of primary energy through our unit area is $\int EF(E)dE$. This energy will eventually all be dissipated in the excitation and ionization of atoms below sea level. If J is the average energy lost in producing one ion pair, and $I(x)$ the observed rate of ionization per unit volume caused by cosmic radiation at a distance x below sea level, then, neglecting the small amount of ionization produced below our unit area by secondary rays which originate above this area, the flux of primary energy is given by

$$\int EF(E)dE = J \int_0^\infty I(x)dx.$$

Thus we can find λ in terms of quantities which may be measured experimentally:

$$\lambda = e\gamma Z^2/2J \int_0^\infty I(x)dx.$$

The values of λ for the processes (a) and (b) may be calculated from the known expressions. Table I contains the

TABLE I.

Values of λ in Meter^{-1} of Water for Energy Lost by Various Processes.

Energy loss by	Electrons	Protons
Radiation	2.2	$2.2/(1840)^2$
Pair Production	0.0073	$0.0073/(1840)^2$
Showers	0.16	

values of λ for these methods of energy loss for protons and electrons in units of meter^{-1} of water. The value of λ which

is to be compared to the 0.3 m^{-1} deduced from the theory of W. F. G. Swann is the sum of the λ's for all processes of energy loss with the exception of the energy lost by ionization and excitation of atoms along the path. Thus, even if we postulate that electrons are unable to produce showers, the total, theoretical λ for electrons is too large. On the other hand, if we assume that showers are not produced by protons, the theoretical value of λ is much too small. Thus it appears that *the soft component of the cosmic radiation consists of primary protons which lose their energy according to the law* $-dE/dx = \lambda E + \alpha$, *where* λE *represents the energy loss by the production of showers.* The value of 0.16 for λ derived from shower data differs from the 0.3 required by Swann's theory only by a factor of two, well within the uncertainty of the data involved in calculating it.

This hypothesis can explain, naturally, an east-west effect due to positively charged particles, which increases with altitude as does the soft component, although the detailed explanation of this effect is much more complicated than is suggested here. The hypothesis is not in contradiction with the recent experiments attempting to detect a proton component of the cosmic radiation, since the actual number of protons passing through an area at sea level will be small compared to the number of secondary rays which accompany them. Thus, although the earth's magnetic field will affect the soft component of the radiation before it enters the atmosphere, and so produce the latitude and azimuthal effects, the cosmic-ray particles which will be observed will be, for the most part, positive and negative electrons: the shower particles which the primary protons have produced.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Hygroscopic Substances in Microanalysis. Part I. New Techniques for Drying and Weighing Solids.—HERBERT K. ALBER (*Mikrochemie*, **25**: 47, 1938). The weighing of hygroscopic solids in various milligram procedures is influenced mainly by the relative hygroscopicity of the substances. To differentiate between the degrees of hygroscopicity, three types of arbitrary standards are established according to the amount of moisture, in micrograms, adsorbed by a 5 mg. sample during a certain time period.

A charging tube with ground cap is described, which offers advantages over the ordinary micro weighing bottles. It serves not only for the weighing of solids of medium hygroscopicity (type B), and partly for those of extremely high hygroscopicity (type C), but also for the exact determination of moisture in organic compounds and biochemical products. For these purposes a metal rack has been designed to serve as holder for the charging tube in the *Abderhalden* drier; by this means the closing of the tube, without access of air to the dried sample, is satisfactorily accomplished.

The techniques of transferring the dried samples to the reaction vessels are described, especially for the more important cases of the nitrogen-Dumas, and the carbon and hydrogen determinations.

Since many hygroscopic substances of biochemical origin have to be analyzed for several elements, a special routine method for these ultimate microanalyses has been carefully tested. An accurate moisture determination is performed with one part of the original sample, using the charging tube with ground cap. Another portion of the same sample is protected from any changes in its moisture content by keeping it in a second charging tube with ground cap; aliquot portions of this sample are used for the various elementary analyses, the results of which are corrected for the dry sample based upon the accurate moisture value. The main advantage

is a considerable saving of time and reduction of manipulative work without impairing the accuracy of the analytical results.

Hygroscopic Substances in Microanalysis. Part II. New Techniques for Drying and Weighing Liquids, Applicable to Micro Preparative Work.—HERBERT K. ALBER (*Mikrochemie*, **25**: 167, 1938). Very little has been published on the handling of hygroscopic liquids for quantitative milligram procedures, i.e., drying, weighing, and transferring to the reaction vessels under complete exclusion of moist air. Therefore, several techniques have been tested and from these five drying procedures were selected, compared and graded according to the amounts of sample available, direct contact with drying agents, complete separation of drying medium and liquid, and specific properties of the liquid compounds, such as hygroscopicity, vapor pressure, and viscosity.

A simple but efficient technique for the automatic filling of weighing capillaries was developed.

In order to compare the efficiency of the various drying procedures, 5 to 10 per cent. by weight of water was added to a set of standard organic liquids of known purity (methyl alcohol, ethyl alcohol, ethylene glycol, glycerol, nitrobenzene, and glyceryl trinitrate); this amount of added water was removed by the appropriate technique. A fractional sample of the final product was analyzed for carbon and hydrogen, or nitrogen, by means of standard micromethods, and the percentages obtained were compared with the percentages found on the original dry sample. The following observations were made during this investigation and indicate some of the factors involved: difficulties with highly hygroscopic liquids (glycerol); incomplete nitration of compounds in their micro preparation (glyceryl trinitrate); reduction of the surface area of the reaction vessel; loss of material in the milligram procedures if only very small amounts of the compound are available; and quantitative evaluation of factors which effect such a loss (evaporation, surface attraction, adsorption). This investigation arose from a comparative study of various decigram, centigram and milligram procedures for micro preparative work.

The Influence of Some Intermediary Metabolites and Salts on the Respiration of Liver Tissue Suspensions.—K. A. C. ELLIOTT AND F. H. ELLIOTT (*Journal of Biological Chemistry*, 114: 457, 1939). The presence of chloride or other univalent anions has been found to be of fundamental importance for the respiration of tissues. Certain simple organic compounds have been shown by previous workers to be constituents of the catalytic systems responsible for respiration. It is now found that their catalytic effect is exerted only in the presence of sufficient chloride or other univalent anion. The effects of univalent anions may explain contradictory results of previous authors.

The rate of respiration of liver suspensions is increased in the presence of chloride or other univalent anions. The respiration can also be increased for a short time by raising the osmotic pressure with glucose. With glucose a higher osmotic pressure is required than with NaCl. The respiration is further increased, and maintained at a high level for a longer period, by the addition of malate, oxaloacetate, citrate, α-ketoglutarate and pyruvate. The action of these substances is completely dependent on the presence of chloride, bromide, nitrate or acetate. Sulfate and phosphate do not produce the increase but rather antagonize the action of chloride. Lactate also increases the respiration but part of the increase, presumably that due to oxidation to pyruvate, is not dependent on chloride. Measurements of R.Q. with livers of normal and starved rats show that the effect of added malate (chloride being present) is largely catalytic and that non-carbohydrate materials as well as carbohydrate derivatives are probably burnt as a result of this catalysis. Some malate is completely oxidized, at least in bicarbonate buffer. Pyruvate and, to a lesser extent, citrate raise the R.Q., and this may be due to the fact that a considerable amount of acetoacetate is formed from pyruvate and some from citrate (the R.Q. for conversion of pyruvate to acetoacetate is 2.0, for citrate it is 4.0). Some β-ketonic acid (acetoacetic) is formed by the respiring tissue,—considerably more when pyruvate is added. The amounts are decreased by the presence of added malate or oxaloacetate. The formation of acetoacetate from pyruvate does not occur in the absence of NaCl. Added oxaloacetate is removed,

mostly by reduction to malate; i.e., it acts as H acceptor, at a very rapid rate, even in the presence of oxygen, yet the initial rate of oxygen uptake is the same as with added malate. The effect of malate is dependent on a certain minimum concentration of tissue. Occasionally livers are obtained with which this limiting concentration is unusually high. The responsiveness to malate keeps for several hours in intact excised liver but is soon lost after dispersion in buffer, even in the cold.

The Effect of Ultraviolet Radiation and of Soft X-rays on the Sedimentation Behaviour and Light Absorption of Purified Human Serum Albumin.—EDWARD B. SANIGAR, LAURA E. KREJCI AND ELMER O. KRAEMER. (*Biochemical Journal*, **33**: 1, Jan. 1939.) Protein solutions are sensitive to ultraviolet light, and are coagulated by irradiation at the isoelectric point. Coagulation can be prevented by irradiating either at reduced temperatures (0–4°) or in the presence of small amounts of acid or alkali, but it then occurs if the temperature is raised or the pH brought to the isoelectric point. It appears that the coagulation of proteins by ultraviolet light takes place in at least two stages, a photochemical reaction independent of temperature, and an aggregation of the molecules attacked, a reaction of comparatively high temperature coefficient.

The ultracentrifugal method of analysis is well-suited to the exploration of a protein system after denaturation since both cleavage and aggregation of the protein molecules will be revealed on the sedimentation diagrams (graphs showing the movement of the boundary of sedimenting material with time of centrifuging) either as distortion of the curves of which the diagrams are composed or as separate maxima on the curves. In view of the importance of actinotherapy in modern curative medicine, an ultracentrifugal and light absorption study has been made of the effects of ultraviolet and soft X-ray irradiations on solutions of purified human serum albumin.

Three series of experiments were made on solutions containing 0.81 g. albumin/100 ml. solution: one near the isoelectric point, at pH 5.4, where the irradiation, performed at

30°, caused ultimate coagulation of the protein, and two at pH 7.4 (normal blood pH), one at 30° and the other at 0° C., where all solutions remained clear. In each series, equal volumes (3 ml.) of protein solution were irradiated by ultraviolet light from a horizontal Uviarc in a rotating quartz tube for various periods of time. The tube used for irradiation was rotated parallel with the arc at about 80 r.p.m. and was at a distance of 20 cm. for the pH 5.4 series, and at 30 cm. for the other two series. The ultraviolet absorption spectra were determined immediately after irradiation by means of Hilger echelon cells (using only 0.5 ml.) with a medium sized Bausch and Lomb quartz spectrograph. The sedimentation velocity determinations were performed the next day, always under identical conditions, after as nearly as possible the same lapse of time, in the Svedberg Oil-turbine ultracentrifuge at 56,000–58,000 r.p.m., corresponding to centrifugal force of about 215,000 times gravity at the middle of the cell. The cell used in the rotor of the centrifuge contained 0.18 ml. of the solution being examined. Sedimentation diagrams and absorption spectra curves are given for the three series of experiments, to show the progressive effect of ultraviolet irradiation upon the serum albumin. A portion of the stock solution of pH 7.4, as used for the ultraviolet irradiations at 30° C., was exposed for as long as 3 hrs. to the continuous radiation from a soft X-ray tube (Cu target, 100,000 V.), the maximum dose being 29,000 r. units (measured with a Victoreen R-meter). No detectable change in either sedimentation velocity or absorption was produced by X-ray irradiation.

It was found that irradiation caused increased light absorption at both pH's, general for wave-lengths longer than 2400Å, but greatest at the protein band (2800Å); the increase was greater at pH 5.4 than at pH 7.4. At pH 7.4, irradiation at 0° caused more increase for wave-lengths above 3000Å, but less increase for wave-lengths below 3000Å than at 30°; after prolonged standing in the cold, the two gave identical spectra. The results indicate that irradiation causes the liberation of small molecular weight substances, and that it also leads to ill-defined photo-oxidation reactions which result in increased light absorption. It is possible

that these reactions may involve both the albumin residues and the low molecular weight cleavage products.

Though visible coagulation occurred only at pH 5.4, irradiation caused aggregation of the protein at both pH's, and gradual reduction in the concentration of unchanged albumin. Aggregation was less pronounced at pH 7.4 than at pH 5.4, and a larger concentration of light-denatured molecules remained unchanged with respect to sedimentation constant. In the absence of a visible precipitate, irradiation led to the formation of successively heavier soluble aggregates, while when visible coagulation occurred the solution was impoverished with respect to soluble aggregates of large size. A correlation was observed between increase of light absorption and decrease in concentration of unaggregated albumin in the irradiated solutions.

The sedimentation constant of the unaggregated protein in the irradiated solutions remained essentially that of native albumin. The sedimentation constant of serum albumin was lower at pH 7.4 than near the isoelectric point; the change (probably in the shape or degree of hydration of the molecule) which caused this difference, appeared to be prevented at low temperatures and to occur rapidly only at temperatures above 23°.

BOOK REVIEWS.

STEEL AND ITS HEAT TREATMENT, by D. K. Bullens. Volume I—Principles, Processes, Control. Fourth Edition, 445 pages, illustrations, plates, 16 ×24 cms. New York, John Wiley & Sons, Inc., 1938. Price $4.50.

Almost everything that surrounds us in our life today traces its manufacture by man to the ability to smelt iron, and to refine and shape it into the many modifications of what is called steel. Any manufactured article may be chosen and then questioned as to whether iron or steel has had anything to do with its appearance in its present form. The answer is convincing. It is indispensable alike in peace and war. Steel that comes direct from the rolls, the forge, or the mold is restricted in use to a very narrow field. Improvement in, and gradation of, the properties of steel, conferred by controlled heating and cooling, fit heat treated steel for myriads of uses which raw steel will not satisfactorily serve. Finer and finer gradations of properties are being and will continue to be demanded by the user of steel and much effort and development must be expended to meet these demands.

This is Volume I of a two volume set of books. It is devoted to those principles, processes, and fundamentals of control which relate to heat treatment of steel in general, including both carbon and alloy steel. Steels that are not amenable to heat treatment are passed by with scant attention. The book is in its fourth edition containing new information and a restatement up-to-date of sound old principles.

There are three sections. The first, on metallurgical principles, begins with an explanation of tests made on steel for various properties, then there follows a description of the constituents of steel with special reference to the changes that take place when steel is subjected to a change in temperature. General annealing practice is given space which concludes with interesting charts containing a condensed summary of the methods of annealing previously discussed. Spheroidizing, normalizing, hardening, tempering and toughening, and grain size are subsequent headings. The last named is a topic under which the greatest advance in theory and practice of heat treatment was had in recent years. The advance is well reflected in the book.

The second section is devoted to surface-reaction processes, the intentional alteration of the surface so as to give the metal hardness and wear resistance. Case carburizing, heat treatment of carburized steel, controlled atmospheres, and cyaniding, nitriding, surface hardening, and coating are topics under this heading. The control of heat treating reactions is section three. Here is pointed out the importance of control from a practical standpoint, the precautions necessary, the proper fuels and furnaces to use, the way to handle furnaces in the application of heat to the charge, control of the cooling phase, and a final word with regard to the human element which enters into the operation of heat treating, and which, it is stated, is a controling factor and the weakest link in present day practice.

The book is a well drawn summary, giving a broad picture of the art. There are given extensive bibliographies from which the material was obtained for the book. Illustrations given are in the form of drawings, curves, and photomicrographs. A subject index completes the book.

R. H. OPPERMANN.

INTRODUCTORY QUANTUM MECHANICS, by Vladimir Rojansky. 554 pages, illustrations, tables, 16 × 23 cms. New York, Prentice-Hall, Inc., 1938. Price $5.50.

The author states that this book is addressed to the reader who wishes to become familiar with some of the simpler physical ideas and mathematical methods of quantum mechanics, either because of his own intrinsic interest, or in preparation for a comprehensive and critical survey of the theory, or for a study of its applications. In order that the book fits securely into this niche, special attention is given in the beginning to the mathematical preparation for its study. The mathematics required for the quantum-mechanical treatment of the motion of a particle is more elaborate than that necessary for the classical treatment of particle motion. Whenever the additional background is necessary, the development is given.

After certain mathematical preliminaries are discussed and remarks made on classical mechanics, quantum mechanical ideas are introduced. This is done by stating the rule of the operator assumption and another rule which requires that quantum-mechanical operators be associated with dynamical variables. Then a description is given of the Schroedinger method of associating specific operators with dynamical variables pertaining to one dimensional systems and not involving explicitly, time. There is constructed the first Schroedinger equation for the case of one dimensional motion. With the completion of this machinery for computing energy levels illustration is given for the case of a linear harmonic oscillator. The third rule which requires that the time dependence of the Schroedinger operands be controlled by a second Schroedinger equation paves the way to develop the technique for handling problems other than those concerning energy levels. Next there is introduced rule IV which implies, in particular, that a Schroedinger function is associated with a state of a dynamical system, and conversely. The final assumption provides the Schroedinger expectation formula, supplying a method for inferring detailed physical information concerning a dynamical system in a certain state from the Schroedinger function which specifies this state. There follows the work of applying the Schroedinger method to a number of one dimensional problems.

The above brief outline is indicative of the general approach throughout the book. Progression is directed along a definite course from which, at times, there are branches with loose ends which are later taken up and adequately treated. The plan of the book provides for the treatment of problems in three dimensional motion, an extension of the Schroedinger method; and the phenomenon of electron spin, including the Pauli theory and the Dirac theory. At appropriate places carefully formulated exercises provide drill in the topics covered.

The book should find use with advanced undergraduate grade students and above and those desiring to become acquainted with the formulation of the theory.

R. H. OPPERMANN.

THE OXIDATION STATES OF THE ELEMENTS AND THEIR POTENTIALS IN AQUEOUS SOLUTIONS, by Wendell M. Latimer. 352 pages, illustrations, tables, 16 × 24 cms. New York, Prentice-Hall, Inc., 1938. Price $3.00.

There are many qualitative questions involved in the interpretation of inorganic chemistry that free-energy data will assist in answering. Those with an elementary knowledge of thermodynamics certainly should welcome this aid in a form easy to get at. There is a large mass of such data scattered throughout the literature and this book has for its aim the gathering together of it and presenting it in a usable manner.

A preliminary chapter explains that the potentials have been derived from four sources; the direct measurement of cells, equilibrium data, thermal data, and approximate limiting values based upon the chemical behavior of a couple with respect to known oxidizing and reducing agents. The importance of considering the values for the ionization potentials and the electron affinities as a contribution to the interpretation of many types of chemical reactions, is early brought to attention, with their relation to the oxidation-reduction potentials of the elements and their compounds. The hydrogen couple is taken as the standard reference electrode and accordingly the book gives proper treatment. Then it proceeds through oxygen and the halogens; the members of Groups 6, 5, and 4 of the periodic system are taken up followed by gallium, indium, and thallium as a separate group because their ions do not have the noble gas structure but are of the so-called "eighteen electron type." The rest of the book is devoted to the other elements.

Free energies of the oxidation-reduction couples, taken with reference to the hydrogen couple, are expressed as volts per equivalent. However, for completed oxidation-reduction reactions, the free energies are given in calories. Solubility products and the dissociation constants of weak acids, bases, and complex ions are in many cases included. Experimental work of the author on the entropies of solids and aqueous ions has furnished the basis for the calculation of many new free energies from reaction heats.

Appendixes give summaries of oxidation-reduction potentials, free energies of formation, equilibrium constants, activity of strong electrolytes and entropy values. There are a great many footnote references throughout the work, a subject, and an author index. The book fulfills its purpose and should be helpful to those interested.

R. H. OPPERMANN.

THEORETICAL MECHANICS, by Carl Jenness Coe. 555 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1938. Price $5.00.

In the 19th century it seems the more that became known of the physical world, the more complicated became its explanation. The old, more-or-less cut and dried classical mechanical theory was consistently questioned as many new phenomena were observed. Using this theory as a basis, exact explanations were sought, but they had to be abandoned. Instead, different types of more complicated mechanical theories were set up resting on entirely new postulates so that at present these may be regarded as different theories, each possessing certain advantages in the degree of accuracy of interpretation. This however,

does not mean that classical mechanics is a thing of the past. While it does not give results which are exactly verified by experiment, the discrepancies are few and extremely difficult to observe. Its study, therefore, is of importance for many practical purposes.

This book presents sufficient material for an introduction to the subject of classical mechanics and through it to mathematical physics. It attempts to make clear the simple postulates on which they rest and at the same time explains and applies the basic principles of vector analysis. There is revealed the special methods and notation of vector analysis which have only recently come into general use in the study of mechanics. After a suitable introduction in which the progression generally is made by defining each new term introduced in terms of previously defined terms and by proving each new theorem on the basis of these definitions and of previously proven theorems, the rectilinear motion of a particle is discussed using only scalar quantities. At this point the introduction to vectors is made and briefly applied to Euclidean and Analytic Geometry in preparation to the next topic, curvilinear motion of a particle where the use of vectors is illustrated similar to that in which scalars were used in the study of rectilinear motion. The illustration is also carried into displacements and motion of a rigid body. A new concept is then formed, that of the sliding vector which is used in the treatments on statics of particles, rigid bodies and the flexible cord. Then there is consideration given to questions of equilibrium which refer to imposed conditions not varying with time, or the principle of virtual work. Chapters on the kinetics of particles and of a rigid body precede a treatment on general principles of mechanics which discusses certain principles or propositions of a noteworthy generality including Lagrange's Equations and Hamilton's Canonical Equations. Finally a discussion of vector calculus leads to a brief exposition of potential theory.

The method of approach and of handling the topics is such as to make for clear understanding. Every sub-section of each chapter is closed with a list of exercises, and there are numerous references and illustrations made to simple conditions in every day life which serve the double purpose of maintaining interest and making an example of the point to be seen. It is so arranged that certain topics may be omitted and more emphasis placed on others.

The material of the book paves the way for a continuation of study in tensor analysis with application to relativity mechanics.

R. H. OPPERMANN.

CHEMISCHE GASREAKTIONEN, von Prof. Dr. H. J. Schumacher. 487 pages, illustrations, tables, 15 × 23 cms. Dresden, Theodor Steinkopff, 1938. Price 33.75 R.M.

The title of this book indicates a very broad and exceedingly important subject that enters into practical application in almost every chemical enterprise. Much of the progress in chemistry may be directly attributed to knowledge of reactions of gases, and it is safe to say that our present knowledge may be taken as the groundwork for a very bright future. In few subjects is there greater truth in the proverb to the effect of a gain in scientific knowledge is merely a stepping stone to greater knowledge.

Written by a man who has had a particularly fruitful experience in this broad field, the book is an up-to-date presentation of the kinetical aspect of the subject. In recent years, with the assistance of the quantum mechanics, numerous investigations were made which cleared up considerable difficulty previously existing, and the work here covers these in the light of present knowledge. It is not, by any means a complete coverage of the existing literature, although quite a large number of references are made throughout. There are given numerous examples of simple reactions, also to a surprising extent the most recent investigations.

The book is divided into two parts, theoretical and experimental. The former deals with the employment of the classical Boltzmann statistics to the speed and energy distribution in ideal gases, a description of the formulas of reaction speed by statistical mechanics, unimolecular reactions, theory of bimolecular reactions, and wave mechanical calculations. The experimental part of the book is so arranged that it dovetails with the theoretical part with the result of facilitating understanding.

The book, entirely in German, covers the subject in a manner flexible enough that conceptions are made from numerous viewpoints. Author and subject indexes enhance its value as a reference.

R. H. OPPERMANN.

THE PERCEPTION OF LIGHT, by W. D. Wright. 100 pages, illustrations, 13 × 19 cms. London, Blackie & Son Limited. Price 6 s.

Those who have to do with artificial illumination, and natural as well, must of necessity become quite familiar with the progress of certain aspects of physiological optics. After all, the basis of good illumination is that which is pleasing to the eye. Here is a little book which has for its purpose the presentation of just that much of visual phenomena that should be considered by illumination specialists. The material is up-to-date and does not have too broad a coverage. It starts out with a general account of visual phenomena, the factors controlling visual sensations, and gives the results of microscopical examination of the retina with regard to vision at the center and periphery of the retina. Then there is an account of vision at low and high intensities, followed by the nature, cause, and measurement of glare. At this point special attention is given to the automobile headlight problem, omitting the relative merits of different types of headlights, but dwelling on the basis on which some figure of merit can be derived.

For many technical problems of illumination, a knowledge of the contrast present between an object and its surroundings is the all-important factor. The determination of the contrast value involves two major problems, (*a*) the definition of the contrast when the sensation magnitudes have been measured, and (*b*) the measurement of the contrasting sensations. These problems are both discussed. A brief presentation of recent researches by a number of workers finishes the book.

The treatment is mostly on the side of physiology. It is light technical reading and the small size of the book, its method of approach with supplemental illustrations should make it profitable for anyone to read.

R. H. OPPERMANN.

NEGATIVE IONS, by H. S. W. Massey. 105 pages, illustrations, 14 × 22 cms. New York, The Macmillan Company, 1938. Price $1.75.

Explanation, in terms of new theories, of physical phenomena and matter has progressed on a wide front almost since the turn of the century. However uniform this front at times has seemed, there are a number of divisions of what might be classed as neglected ends, which still need investigation to place them on an equal footing with the larger aspects of the subjects that have been revised. One of these is the subject of negative ions, the existence of which was conceived early. Although there has been considerable study of this subject, it is very much open to further investigation.

This little book is a part of a series of tracts on subjects of current physical interest. It is composed of a survey of the present state of knowledge of the subject and a discussion on the nature and properties of negative ions gained from experiment and from theoretical considerations by means of the use of the quantum theory. The coverage is concerned particularly with negative ions formed in gases at pressures up to a few mm. Hg, as differentiated from ion clusters. The exitence of negative ions formed by atoms is described by referring to recent experiments. The application of the quantum theory is then made in explanation of the negative ion. There follows a discussion of methods available for the determination of electron affinities, experimental as well as empirical. This ends the first chapter.

An accounting is then given of the motion of the nuclei with respect to the structure of negative ions formed by molecules, and other related matter on the general topic of negative molecular ions. This precedes consideration of the processes which lead to negative ion formation and which is restricted to those already observed experimentally but making use of the results both of theory and experiment. Here there is listed nine different processes that can give rise to negative ions and the comments on these give the most probable under certain conditions. Under the heading of detachment of electrons from negative ions use is made of the fact that corresponding to each attachment process there is one of detachment which is the thermodynamic reverse and the probabilities may be related by considerations of microscopic reversibility. In the last chapter of the book there is pointed out likely avenues for further investigation of negative ions in glow discharges and in the upper atmosphere.

The book is a timely presentation and should greatly assist in work relating to the subject.

R. H. OPPERMANN.

TECHNICAL DRAWING PROBLEMS, by Frederick E. Giesecke, Alva Mitchell and Henry Cecil Spencer. 92 pages, 24 × 28 cms. New York, The Macmillan Company, 1938. Price $2.25.

This book is designed to be used as a work book in conjunction either with the authors' text "Technical Drawing" or with other good works. It consists of a number of problems divided into groups which cover such subjects as instrumental exercises, geometric constructions, lettering exercises, surface and edge identification problems, auxiliary views, isometric drawings, etc. These are located in the front of the book and the directions for carrying out the work

refer to some 93 work sheets which contain basic drawing material and which comprise the rest of the book. The problems are well chosen. References are made in the exercises to sections and paragraphs in the authors' text so that an adequate appraisal of this book, and also its use to the fullest extent, requires it to be viewed as supplementary to the forementioned text.

R. H. OPPERMANN.

BLÄTTER FÜR GESCHICHTE DER TECHNIK. Fünftes Heft. Schriftleitung: O. O. Prof. Dr. K. Holey. 137 pages, illustrations, 18 × 25 cms. Wien, Julius Springer, 1938. Price 6 R.M.

The January 1939 number of the JOURNAL OF THE FRANKLIN INSTITUTE contained mention of the fourth of this series of booklets. This is the fifth and is of similar composition. It opens with a memorial to technical culture by Prof. Dr. phil. h.c. Dr. Ing. Eh. Conrad Matschoss V.D.I. Berlin. This is followed by a presentation of Ing. Dr. Karl Holey on technical development in Austria and their utilization by the people, in which stress is laid on power development by water and wind, and some brief mention made of the uses of such power. Oberinspektor Ing. Josef Sames of Linz then carries this forward. The work of two skilled mechanics, Ludwig Knaus and Friedrich von Knaus is described by Ing. Erich von Kurzel-Runtscheiner, followed by that of Josef Werndl by Ing. Viktor Schutzenhofer which relates to the development of fire arms. Other fields of endeavor in which contributions were made by Austrian engineers and scientists including highways and the motor car, city planning and city industries, and a general description of the adaptation of the country to technical developments—all are given illuminating explanations. The booklet is illustrated with pictures of old and new scenes in various parts of Austria in which work of this nature was undertaken. Judging from the two booklets of this series that have been examined, the series should contain a comprehensive story of Austria's part in the world of scientific and engineering accomplishments.

R. H. OPPERMANN.

PHOTOGRAPHY, ITS PRINCIPLES AND PRACTICE, by C. B. Neblette. Third Edition, 590 pages, illustrations, 16 × 24 cms. New York, D. Van Nostrand Company, Inc., 1938. Price $6.50.

Photography today plays a very important part in every day life, in industry, and in science. It is one of those things that has entered into the life of the layman, has been accepted, and even taken for granted. Hobbyists and professional photographers have had opportunity to take note of the advance of photography in recent years which has been the corner stone of its popular acceptance. This advance, too, is becoming of greater service to industry and science as the possibilities for its use become recognized. But even now the state of knowledge of the subject may be said to be, in a sense, unbalanced. True, there is much widespread knowledge and activity in the practice of photography. The science of photography, however, compared with other sciences, is still somewhat restricted in the spread of knowledge. There has not been so much accomplished in the way of formal instruction which is reflected in the literature, although in the last decade considerable increase in publications has been noted.

The first edition of the book appeared in 1927, the second in 1930, and now there is the third. Between the second and third editions, probably the greatest developments in photography took place. The present book reflects this advance. Written by the Administrative Head, Department of Photographic Technology, Rochester Athenæum and Mechanics Institute, it is in the form of a text, and contains the features acquired from giving formal instruction in the subject. The quality of the entire work is very well illustrated in the very first chapter which is on the history of photography. The coverage of some 42 pages gives an account from about 350 B.C. to the development of the Kodachrome film, that is second to none for completeness in-so-far as the recording of the outstanding developments is concerned, and for interesting detail. The text proper follows, starting with the camera and photographic optics, and proceeding through such subjects as photographic emulsion, reproduction of tone and color, negative materials, theory of development, printing processes, mounting, etc. Everything is covered that should be in a work of this kind. The material is theoretical in nature as well as practical. Careful illustrations in the way of drawings and photographs appear where necessary to assist in clarification. Reference is made throughout the text, by means of footnotes to some of the more complete and useful papers which are readily available for further perusal. There is a comprehensive subject and author index.

Being primarily a text for college grade students, a foundation of physics and chemistry is presupposed. These are necessary to absorb the contents in their entirety. A large portion of the book gives practical instruction as well, so-much-so that the non-technical reader can profit by it. The most favorable feature is clarity of presentation. After this may be placed the logical order of topics and the progression from the simple to the more complex in each.

R. H. OPPERMANN.

FUNDAMENTAL ELECTRONICS AND VACUUM TUBES, by Arthur Lemuel Albert. 422 pages, illustrations, 16 × 24 cms. New York, The Macmillan Company, 1938. Price $4.50.

For some period of years after practical application was made of the electron tube, the subject of electronics was considered apart from the curriculum of electrical engineering. The applications have become so numerous and diversified and the subject so closely related that it is now recognized as much a part of electrical engineering as any of the other basic and branch subjects. This is true whether a student be majoring in electric power or communication.

The author of the book has planned it so that it is primarily directed to undergraduate students. It is devoted to a study of fundamentals of electronics, to the application of these principles to vacuum tubes and associated devices, and to the uses of these tubes and devices in electric circuits. The treatment starts with a statement of the basic laws of electronics stressing two important subjects, electronic phenomena in gases and electronic phenomena in solids, which is followed by consideration of the release of electrons by photons of light striking certain metals, by heating of the metals to high temperatures, by directing streams of rapidly moving electrons against metals, by subjecting the surface of a metal to strong electric fields, and by chemical action. Thermionic emission is then

covered in detail, first the principles, then their application in two and three element tubes. When the subject of multi-electrode tubes is discussed, attention is centered on the fundamental electronic principles as here-to-fore rather than on the tubes individually. This is done by dividing the tubes into two classes—those which are designed to perform some function which cannot be performed readily by a triode or which will perform some function better than will a triode, and those having additional electrodes to permit them to perform simultaneously more than one function or permit them to function in two or more ways.

What may be taken as the second part of the book is that on the application of the tubes. It begins with a treatment on application in rectification and proceeds through voltage and power amplifiers, oscillators, modulators and demodulators. In another direction, photoelectric devices and circuits is discussed, referring to the theories underlying these photoelectric phenomena in the beginning of the book, and giving the characteristics of these devices and their uses. Finally there is presented the theory of cathode-ray tubes, their application, and the application of other electronic devices to circuits for electrical measurements.

At the end of each chapter there is a list of references covering the topic and suggested assignments comprising carefully composed questions. The book is well illustrated and contains a subject index. In addition to its being worth consideration as a class room text, it is a valuable book for the practicing engineer for study in case there is a need for formal training, as well as for reference.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 630, A Flight Comparison of Conventional Ailerons on a Rectangular Wing and of Conventional and Floating Wing-Tip Ailerons on a Tapered Wing, by H. A. Soule and W. Gracey. 5 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

Flight tests comparing the relative effectiveness of conventional ailerons of the same size on wings of rectangular and tapered plan forms were made with a Fairchild 22 airplane. Information is included comparing conventional and floating wing-tip ailerons on a tapered wing. The results showed that the conventional ailerons were somewhat more effective on the tapered than on the rectangular wing. The difference, however, was so small as to be imperceptible to the pilots. The floating wing-tip ailerons were only half as effective as the conventional ailerons and, for this reason, were considered unsatisfactory.

Report No. 639, The Effect of Compressibility on Eight Full-Scale Propellers Operating in the Take-Off and Climbing Range, by David Biermann and and Edwin P. Hartman. 29 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

Tests were made of eight full-scale propellers of different shape at various tip speeds up to about 1,000 feet per second. The range of blade-angle settings investigated was from 10° to 30° at the 0.75 radius.

The results indicate that a loss in propulsive efficiency occurred at tip speeds from 0.5 to 0.7 the velocity of sound for the take-off and climbing conditions.

As the tip speed increased beyond these critical values, the loss rapidly increased and amounted, in some instances, to more than 20 percent of the thrust power for tip-speed values of 0.8 the speed of sound. In general, as the blade-angle setting was increased, the loss started to occur at lower tips speeds. The maximum loss for a given tip speed occurred at a blade-angle setting of about 20° for the take-off and 25° for the climbing condition.

Although the loss at the take-off condition due to compressibility was greater for the R.A.F. 6 section than for the Clark *Y*, greater for blades of standard width than for extremely wide ones, and greater for a thick propeller than for a thin one, the actual efficiencies at high tip speeds were found to be about the same because, in each case, the propeller that had the greatest losses from increasing the tip speed had the highest efficiency at low tip speeds.

The compressibility loss at the take-off for controllable propellers was considerably reduced because of decreased blade-angle operation necessitated by increased power coefficients, but the reverse was true for fixed-pitch propellers inasmuch as the higher power coefficients resulted in reduced engine speeds.

A simplified method for correcting propellers for the effect of compressibility is given in an appendix.

Report No. 642, Tests of Five Full-Scale Propellers in the Presence of a Radial and a Liquid-Cooled Engine Nacelle, Including Tests of Two Spinners, by David Biermann and Edwin P. Hartman. 27 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

Wind-tunnel tests are reported of five 3-blade 10-foot propellers operating in front of a radial and a liquid-cooled engine nacelle. The range of blade-angles investigated extended from 15° to 45°. Two spinners were tested in conjunction with the liquid-cooled engine nacelle. Comparisons are made between propellers having different blade-shank shapes, blades of different thickness, and different airfoil sections.

The results show that propellers operating in front of the liquid-cooled engine nacelle had higher take-off efficiencies than when operating in front of the radial engine nacelle; the peak efficiency was higher only when spinners were employed. One spinner increased the propulsive efficiency of the liquid-cooled unit 6 percent for the highest blade-angle setting investigated and less for lower blade-angles. The propeller having airfoil sections extending into the hub was superior to one having round blade shanks. The thick propeller having a Clark *Y* section had a higher take-off efficiency than the thinner one, but its maximum efficiency was possibly lower. Of the three blade sections tested, Clark *Y*, R.A.F. 6, and N.A.C.A. 2400–34, the Clark *Y* was superior for the high-speed condition, but the R.A.F. 6 excelled for the take-off condition.

Report No. 644, The Torsional and Bending Deflection of Full-Scale Aluminum-Alloy Propeller Blades under Normal Operating Conditions, by Edwin P. Hartman and David Biermann. 8 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

The torsional deflection of the blades of three full-scale aluminum-alloy propellers operating under various loading conditions was measured by a light-

beam method. Angular bending deflections were also obtained as an incidental part of the study.

The deflection measurements showed that the usual present-day type of propeller blades twisted but a negligible amount under ordinary flight conditions. A maximum deflection of about 1/10° was found at a V/nD of 0.3 and a smaller deflection at higher values of V/nD for the station at 0.70 radius. These deflections are much smaller than would be expected from earlier tests, but the light-beam method is considered to be much more accurate than the direct-reading transit method used in the previous tests.

Report No. 645, Correction of Temperatures of Air-Cooled Engine Cylinders for Variation in Engine and Cooling Conditions, by Oscar W. Schey, Benjamin Pinkel, and Herman H. Ellerbrock, Jr. 24 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 15 cents.

Factors are obtained from semiempirical equations for correcting engine-cylinder temperatures for variation in important engine and cooling conditions. The variation of engine temperatures with atmospheric temperature is treated in detail, and correction factors are obtained for various flight and test conditions, such as climb at constant indicated air speed, level flight, ground running, take-off, constant speed of cooling air, and constant mass flow of cooling air.

Seven conventional air-cooled engine cylinders enclosed in jackets and cooled by a blower were tested to determine the effect of cooling-air temperature and carburetor-air temperature on cylinder temperatures. The cooling-air temperature was varied from approximately 80° F to 230° F. and the carburetor-air temperature from approximately 40° F. to 160° F. Tests were made over a large range of engine speeds, brake mean effective pressures, and pressure drops across the cylinder. The correction factors obtained experimentally are compared with those obtained from the semiempirical equations and a fair agreement is noted.

PUBLICATIONS RECEIVED.

La Mecanique Ondulatoire des Systemes de Corpuscules, by Louis de Broglie. 223 pages, illustrations, 17 × 25 cms. Paris, Gauthier-Villars, 1939. Price 100 francs.

Steel and its Heat Treatment, by D. K. Bullens. Volume II—Engineering and Special-Purpose Steels. Fourth Edition, rewritten and reset. 491 pages, illustrations, tables, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1939. Price $5.00.

Photographic Chemicals and Solutions, by J. I. Crabtree and G. E. Matthews. 360 pages, illustrations, 17 × 25 cms. Boston, American Photographic Publishing Company, 1939. Price $4.00.

Radio Trouble-Shooter's Handbook, by Alfred A. Ghirardi. First Edition, 518 pages, illustrations, 23 × 29 cms. New York, Radio & Technical Publishing Co., 1939. Price $3.00.

The Engineers' Manual, by Ralph G. Hudson. Second Edition, 340 pages, illustrations, tables, 13 × 20 cms. New York, John Wiley & Sons, Inc., 1939.

General and Inorganic Chemistry, by Frederick C. Irwin and G. Ray Sherwood.

583 pages, plates, illustrations, 16 × 22 cms. Philadelphia, P. Blakiston's Son & Co., Inc. Price $3.50.

Tensor Analysis of Networks, by Gabriel Kron. 635 pages, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1939. Price $7.50.

Physico Chemical Experiments, by Robert Livingston. 257 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1939. Price $2.25.

The Principles of Electrochemistry, by Duncan A. MacInnes. 478 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1939. Price $6.00.

The Geometry of Determinantal Loci, by T. G. Room. 483 pages, illustrations, 19 × 28 cms. New York, The Macmillan Company, 1938. Price $10.

Polycyclic Aromatic Hydrocarbons, by Ch. Weizmann and E. Bergmann. 35 pages, illustrations, 17 × 25 cms. Jerusalem, Scripta Academica Hierosolymitana, 1938.

The Structure and Composition of Foods, by Andrew L. Winton and Kate Barber Winton. Volume 4, Sugar, Sirup, Honey, Tea, Coffee, Cocoa, Spices, Extracts, Yeast, Baking Powder. 580 pages, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1939. Price $9.00.

The Indian Academy of Sciences. Sir Chandrasekhara Venkata Raman, 1888 to November 7, 1938. Jubilee volume of original papers presented in commemoration of his fiftieth birthday. 322 pages, illustrations, plates, 20 × 27 cms. Bangalore, Academy, 1938.

Association Internationale d'Hydrologie Scientifique. Bulletin N. 23, Sixieme Assemblee Generale a Edimbourg du 14 au 26 Septembre 1936: II, Partie des Travaux de l'Association. Transactions of the Meetings of the International Commissions of Snow and of Glaciers. Riga, Association, 1938.

National Advisory Committee for Aeronautics. Technical Notes: No. 682, The Unsteady Lift of a Finite Wing, by Robert T. Jones. 19 pages, illustrations. No. 683, Pressure-Distribution Measurements on a Tapered Wing with a Full-Span Split Flap in Curved Flight, by Th. Troller and F. Rokus. 16 pages, illustrations. No. 685, Circulation Measurements about the Tip of an Airfoil during Flight through a Gust, by Arnold M. Kuethe. 26 pages, illustrations. Three phamphlets, 20 × 26 cms. Washington, Committee, 1939.

Bell Telephone System, Monographs: B-1096, Correlation of Optical Properties and Photoelectric Emission, by Herbert E. Ives and H. B. Briggs. 21 pages, illustrations. B-1102, The Dielectric Properties of Insulating Materials—II, by E. J. Murphy and S. O. Morgan. 30 pages, illustrations. B-1104, Effect of Space Charge and Transit Time on the Shot Noise in Diodes, by A. J. Rack. 28 pages, illustrations. B-1105, Fundamentals of Teletypewriters Used in the Bell System, by E. F. Watson. 20 pages, illustrations. B-1108, Paper as a Medium for Analytical Reactions, by Beverly L. Clarke and H. W. Hermance. 26 pages, illustrations. B-1109, Measurement of Absorption in Rooms with Sound Absorbing Ceilings, by J. R. Power. 8 pages, illustrations. B-1110, Noise Co-ordination of Rural Power and Telephone Systems, by H. W. Wahlquist and T. A. Taylor. 15 pages, illustrations. B-1111, Effect of Temperature on the Mechanism of Oxidation of Rubber, by J. H. Ingmanson and A. R. Kemp. 14 pages, illustrations. B-1112, An X-Ray Test of Superstructure in $FeNi_3$, by F. E. Haworth. 14 pages, illustrations. Nine pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1938.

CURRENT TOPICS.

Radium Protection.—The rapid increase in the use of radium during the last few years, resulting in the acquirement of large amounts of radium by various institutions, has brought with it the need for better safeguards and rules to protect the users from the radiation. The dangers arising from exposure to the radiation from radium are in some cases now well known, in others, still obscure and uncertain. Sufficient experience and data are now available, however, to show fairly conclusively that with reasonable precautions radium can be handled over a considerable period of years with no apparent harm. On the other hand, serious injury has resulted from relatively short periods of work with radium where certain precautions were overlooked. Even when proper working conditions and suitable regulations exist, there is still the potential danger of excessive exposure as a result of improper use of safety equipment and violation of good practice. Since the injury does not become apparent immediately, workers may frequently be tempted to neglect routine precautions. The regulations set forth in the National Bureau of Standards Handbook H23 which supersedes H18 are the result of work done jointly with the Advisory Committee on X-ray and radium protection.

R. H. O.

Possibilities for Utilization of Pulverized-Coal Ash.—A. W. Thorson and J. S. Nelles. (*Mechanical Engineering*, Vol. 60, No. 11.) The disposal of fly ash collected from pulverized-coal-fired boilers is a problem of general concern to the central station industry. For the past ten years The Detroit Edison Co. has been seeking a market for the quantity disposal of fly ash collected at its Trenton Channel Power House. The investigation of possible uses for the ash showed that it can be used as a filler in asphalt paving, agricultural fertilizer, and paint and putty; as an aggregate in Haydite concrete, fly-ash-cinder concrete, and Cottrell block; as an admixture in concrete; as an abrasive for sand blasting; as a raw material in the manufacture of Portland cement; and as an insulating material in the cells of hollow masonry walls. Because of local conditions in the Detroit area, effort has been concentrated toward development of projects using Cottrell block, fly-ash-cinder concrete, concrete admixture and asphalt paving. Although The Detroit

Edison Co. is pinning its hope to these possibilities of solving its ash disposal problem, all these uses depend on cyclic activity of the building industry. Another completely independent usage which will absorb the ash not used by the building industry is highly desirable.

R. H. O.

Production of Hydrogen Aided by New Catalyst.—(*The Gas Age*, Vol. 82, No. 10.) At the Reich Workers' Meeting of German Chemists in Bayreuth "New Processes for the Production of Hydrogen from Hydrocarbons" was the subject of a paper by G. Schiller, Ludwigshafen. The direct decomposition of methane into carbon and hydrogen is no longer considered by new plants. The catalytic process for the reaction of hydrocarbons with steam—for example $CH_4 + H_2O = CO + 3H_2$—has come into practical use with the introduction of an improved catalyst (activated nickel) which functions at a sufficiently low reaction temperature (600° to 800° C.). In this process there is no soot formation during the conversion of hydrocarbons of high molecular weights, such as those which occur in refinery waste gas and in waste gas from the hydrogenation of coal and oil. The cracked gas still contains 1.5 to 2 per cent. of methane. After conversion of the carbon monoxide with steam the hydrogen is sufficiently pure for hydrogenation purposes.

R. H. O.

Tunnels Add to Value of Modern Highways.—Highway tunnels were once rare because of their cost. But within recent years the U. S. Bureau of Public Roads has constructed in Federal areas, or aided the States in the construction of, 24 major highway tunnels in the Western States. Speed and volume of traffic have increased and the steep and winding roads once built in the mountains often can be avoided only by boring a tunnel. In general, construction of an open cut is more economical than tunneling if the length is less than 80 feet or if the cut can be made by excavating not more than 80 feet deep. Most of the important tunnels range from 200 to 1,000 feet in length, but there is one in Zion National Park over a mile in length. The Wawona tunnel in Yosemite National Park is nearly a mile long. Tunnels vary greatly in difficulty of construction and in cost. A short tunnel through solid rock may be built for $75 to $100 per lineal foot. If the rock is broken so that it falls, or the tunnel is through earth, lining is required. A reinforced concrete lining may more than double the cost. Nineteen

of the twenty-four tunnels referred to had to be lined. The longer tunnels must be ventilated, sometimes by side openings or by shafts that act like chimneys and sometimes by forced drafts from large fans. Lighting of tunnels is becoming a frequent practice.

R. H. O.

Device Detects Mercury Vapor in Air.—(*Electrical World*, Vol. 110, No. 19.) One part of mercury vapor in a hundred million parts of air by volume can be detected and registered by a simple new device developed by the General Electric Co. This device makes use of the property of selenium-sulphide to turn dark brown when exposed to metallic mercury vapor. The degree of darkening depends upon the mercury vapor concentration, the velocity of air passing over the sensitive chemical, the temperature of the air and the time of exposure. The detector is essentially a truncated cone of aluminum, supported by a Mogul base over a 25 watt red incandescent lamp. Fastened to the top of the cone is a holder accommodating strips of selenium-sulphide treated sensitized paper. A reasonably constant temperature and an upward flow of air through the cone and past the paper is provided by the red lamp in the cone's base. Air other than that from the cone is prevented from striking the paper by a cylinder mounted around the holder and fitted with a window that permits access to the paper holder. A calibrated color chart is used with the detector. This chart has a horizontal scale consisting of six shades of brown for matching with the exposed paper, and a vertical scale that gives the concentration of mercury vapor in the air. Knowing the number of hours exposure of the paper its color can be matched with those on the chart and the mercury vapor concentration determined. Natural color of the unexposed selenium-sulphide paper is a light yellow. The coating turns pink when exposed to high temperatures or actinic light, hence the red rather than the clear bulb.

R. H. O.